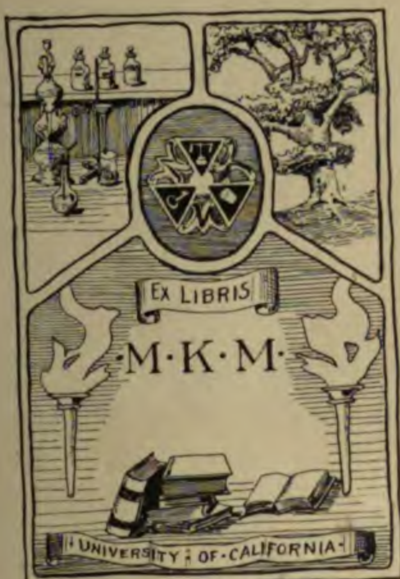
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AGRICULTURE

IN SOME OF ITS RELATIONS WITH

CHEMISTRY

BY

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IN TWO VOLUMES

VOL. I.

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To my Father,

DR. D. HUMPHREYS STORER,

THESE VOLUMES

ARE AFFECTIONATELY INSCRIBED.

TO HIS ZEALOUS EXAMPLE AND CONSTANT ENCOURAGEMENT ARE
TO BE ATTRIBUTED WHATEVER OF SCIENTIFIC
PURPOSE MAY BE FOUND IN THEM.

F. H. S.

PREFACE.

THIS book has been written in the interest of persons fond of rural affairs, and of students of agriculture. It makes no special appeal to chemists or to students of chemistry. It is based upon lectures, suggestive rather than encyclopedic, which have been delivered annually by the author at the Bussey Institution during the past sixteen years (1871–1887). These lectures, which have been many times altered and revised, were addressed to small classes of students of two distinct types, viz.: first, young farmers, and sons of farmers, familiar with the manual practice of agricultural operations, who were desirous of studying some of the sciences which bear most immediately upon the art of farming; and, secondly, city-bred men, — often graduates of the academic department of the University, — who intended either to establish themselves upon farms, or to occupy country seats, or to become landscape gardeners.

It should be said that the present publication of a part of the matter thus accumulated is wholly an afterthought, suggested by the recent solicitations of students. But it is hoped that the work may appeal to many members of that large class of practical farmers, interested in scientific agriculture, who cannot possibly find time to leave home to study it.

The author desires to acknowledge his indebtedness to his teachers Stoeckhardt and Boussingault, and to the publications of Malaguti, Mulder, Bobierre, Wolff, A. Mayer, and Sachs, and especially to those of Knop,* Heiden,† and Hellriegel.‡

* Lehrbuch der Agricultur-Chemie, 8vo, 2 vols.

† Lehrbuch der Düngerlehre, Stuttgart, 3 vols.

‡ Beiträge zu den naturwissenschaftlichen Grundlagen des Ackerbaus, Braunschweig, 1883.

Like all other agricultural chemists, he owes a great debt of gratitude to the collaborators of the Jahresbericht and the Centralblatt der Agricultur-Chemie, which were established respectively by R. Hoffmann and R. Biedermann.

Special mention needs to be made of the publications of his friend, Prof. S. W. Johnson, of New Haven. The long series of essays by this chemist which have appeared in the American Journal of Science, and the Reports of the State Board of Agriculture of Connecticut, and of the State Board of Control of the Agricultural Experiment Station at New Haven, constitute by far the most important contributions to agricultural science hitherto made by an American. They have from the first most deservedly been held in high esteem both by scientific men and by practical farmers. Free use has been made of these papers in the preparation of the present book.

With regard to the books of Professor Johnson, notably those entitled "How Crops Grow," and "How Crops Feed," — which it is fair to presume are already in the hands of almost every student of agriculture, — the author would urge upon the reader, as he has been accustomed to urge upon his pupils, the great importance both of studying these treatises for their own sakes, and of consulting them freely in elucidation of many subjects which are treated of in the present work. Not a few points have here been lightly touched upon, or even wholly omitted, simply because full explanations concerning them may be found in one or another of Johnson's books.

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AGRICULTURE.

CHAPTER I.

GENERAL RELATIONS OF SOIL AND AIR TO THE PLANT.

On considering the relations in which plants stand to the air and the soil which surround them, the questions naturally arise, What are the sources from which plants derive food? and, How is it that plants take in their food?

Suppose, for example, that a seed was buried in the earth some time since, that it has germinated there, and that the plant has begun to grow independently, of what significance for this plant are the soil and the air with which it is in contact?

Strange as it may seem on first sight, it is from air and from water that plants are chiefly derived. All the so-called carbonaceous matters in a plant are formed from carbonic acid which is taken into the plant through the leaves. From the air, too, comes the larger part of the oxygen which next to carbon is the predominant constituent of the dry matter in plants. Boussingault found in a crop of 4,500 lb. of clover hay harvested from an acre of land

1680 lb. of carbon,	177 lb. of hydrogen, and
1340 lb. of oxygen,	74 lb. of nitrogen.

Plants contain much Water.

A fresh or living plant consists largely of mere water. Young grass, for example, is three fourths water, which may be dried out at 212° F. Potatoes also contain almost 75% of water, and the more succulent vegetables contain a still larger proportion. Beets and carrots contain 80 or 90% of water. A 2,000 lb. ton of turnips may contain more than 1800 lb. of water. Even trees seldom contain less than one third their weight of it. Schübler found that ash trees felled at the end of January contained 29% of water, a

maple 34%, and a fir 53%. The same kinds of trees felled early in April had 39, 40, and 61% of water respectively. Gelesnoff, who made determinations for every month in the year, found that the average yearly amount of water in a pine tree was 61%, in a poplar 53%, in a birch 49%, and in a maple 42%.

This water comes from the soil, i. e. it is taken into the plant through the roots. From the soil also the roots of plants take in that small proportion of inorganic matter which is left as ashes when the plant is burned. Every hundred pounds of the clover hay examined by Boussingault contained some six pounds of ashes. From the soil come also the salts of nitric acid or of ammonia, or the other nitrogen compounds of whatever name, which go to form the nitrogenized constituents of the plant, as will be seen hereafter.

Water Culture.

It is quite possible to make plants grow tolerably well without the intervention of any soil, using the term soil of course in its ordinary acceptation.

Not only do we see parasitic plants, like the mistletoe and Spanish moss, growing freely in mere air, but it is easy to make a great variety of plants grow in water. It has long been customary in domestic horticulture to grow hyacinths and other bulbs, as well as cuttings of rosebushes and of the so-called Wandering-Jew (*Tradescantia*), in glasses of water, and it is true that almost any of the ordinary grains may be made to grow and bear seeds in this way, Indian corn notably. It is only necessary that the water shall hold dissolved certain so-called inorganic, or ash-producing, constituents of the plant, and a small quantity of some compound of nitric acid, the very things, namely, which are ordinarily taken by the plant from the soil. Though these soil-derived substances are few in number, and though the quantity of each of them required by a plant is exceedingly small, they are none the less essential and indispensable.

It is impossible for plants of the higher orders to develop themselves in the absence of potash, lime, magnesia, iron, phosphoric acid, sulphuric acid, and chlorhydric acid, and some nitrogen compound, such as one of nitric acid or of ammonia.

We know thus much not only from the fact that the substances in question (excepting the nitrogen compounds) are always to be found in the ashes of plants; but, better, we know it from the

results of manifold experiments made with factitious soils, in the compounding of which one or more of the substances enumerated were left out.

Even the parasitic plants, like the mistletoe, take food from the sap of the tree to which they are attached, or from the decaying wood itself in case they grow upon a lifeless branch.

History of Water Culture.

The method of "water culture," just now alluded to, has acquired a good deal of importance of late years. Many experiments of great value for the elucidation of questions in vegetable physiology have been tried by means of it.

The idea itself is old. The Swiss naturalist Bonnet studied it long ago. So too, as early as 1758, the French chemist and botanist Duhamel grew beans in this way, and he produced chestnut, oak, and almond trees. Some of his trees were six and eight years old when an accident destroyed them. Duhamel found that it was necessary to change the water frequently, and we now know that it is the matters in the water, the substances namely which are held dissolved in the water, that need to be renewed.

In experimenting in this way it is no longer customary to take spring water, but pure distilled water, in which can be dissolved whatever substances we may wish to experiment upon. The subject is described in some detail in Professor S. W. Johnson's book entitled "How Crops Grow," under the head of "Water Culture."

Sand Culture.

Instead of placing the clear aqueous solution to be experimented upon in a jar by itself, it might be poured into a vessel filled with pulverized quartz, or with any other inert substance incapable of yielding plant-food, such as beach sand which has been leached with an acid. If this be done, it will be found that plants will grow in the mixture very much in the same way that they grow in the water without the sand, excepting that in the sand the plant provides for its own mechanical support.

The use of sand in this way is closely allied to a common method employed by gardeners in their propagating-houses, though the object of using sand in this case is to "start" cuttings in a soil free from any putrescible matters which might make the cuttings rot.

So too, in Holland, gardeners grow the bulbs of flowering plants on the large scale, and very superior potatoes also, on the sand dunes of that country, after having heavily manured them. The

mobile sand allows the roots and tubers to develop smoothly and symmetrically, i. e. an unusually large proportion of the sand-grown crop is free from blemishes or irregularities of form.

Many experiments have been made in this way by scientific men also. For example, the German chemists Wiegmann and Polstorff, in order to obtain an absolutely inert sand, cut a quantity of platinum wire into small pieces; they put the fragments in a platinum cup together with a definite number of seeds of the common cress (Lepidium sativum) and they moistened the wire with pure distilled water. The cup was then put under a bell glass, to protect its contents from dust, and the air of the bell glass was kept fresh, and proper for the growth of the seeds.

The seeds germinated, grew naturally during some days, and even reached a height of three inches before they began to droop and die. On igniting the cup and its contents so that the plants were burned to ashes, these ashes were found to weigh precisely as much as the ashes obtained from another lot of seeds, equal in number to those sown upon the platinum. This experiment is here cited merely in illustration of the method of research. The real object of the experiment was to determine precisely what happens when a seed is made to sprout in a soil destitute of plant-food. It helps to enforce the lesson, which has been learned from many other observations, that, for continuous growth, food must be supplied continually. If there had been dropped upon the platinum sand a mixture of the needed ingredients, the plants would have grown well enough, and would even have formed perfect seeds.

Uses of the Soil.

It would appear that ordinary earthy soil is of use primarily as standing room; the roots of plants spreading among the minute particles of which the soil is composed adhere to them in such wise that the plant is held securely in the position proper to it. The plant is braced and ballasted. It is evident, moreover, that soils from which crops are to be taken must contain in some shape the ash-producing ingredients proper to those crops.

Assimilation of Plant-Food.

The questions still remain to be answered, In what state is the plant-food contained in the soil? and, How does the plant get at its food?

The weight of evidence thus far accumulated goes to show that the plant-food passes from the soil into the plant in the form of a

solution. But it is by no means universally true that all the food consumed by a crop is in a state of solution in the soil, ready and waiting to flow towards the roots and to enter the plant when needed. Some plant-food — especially some particular kinds of plant-food — is undoubtedly held in solution in the moisture of the soil, so that the earth of cultivated fields is not wholly dissimilar to the moistened sand of the greenhouse men and of the scientific experimenters. But it would be highly erroneous to regard the soil as if it were nothing more than a sort of sponge charged with solutions of substances proper for the growth of plants. Really, the soil, beside being a storehouse from which plant-food is derived, is a laboratory in which solutions of plant-food are compounded; and, in addition to all this, it is known that the roots of plants, or rather matters exuded from the roots, play a very important part in dissolving substances out of the earth which mere water would be incapable of dissolving. The little hairs, in particular, upon the roots which cling so tightly to the soil, are active agents both for absorbing food from the soil-water and for dissolving food from the soil.

The earth serves also to arrest and retain many substances excluded by the plant which would do harm if they were suffered to remain dissolved so that they could accumulate about the roots. One of the chief difficulties inherent to the method of experimenting by water culture is precisely this accumulation of hurtful matters in the solutions used, as will be explained hereafter.

Diffusion and Osmose.

Nevertheless, for the sake of the argument, it may perhaps be well at first to consider the soil as if it were merely a source or reservoir of saline solutions,—which indeed it most truly is, as well as something more. This supposition will afford a convenient basis for the inquiry as to the manner in which the plant receives its food, and lead directly to a brief consideration of the laws of Osmose and of the diffusion of liquids, which control the admission of food to plants.

It is a matter of experience, that, if some salt be placed at the bottom of a tall jar, and the jar be then quietly filled with water and left at rest in a place of constant temperature, a perfectly homogeneous solution of salt and water will be obtained, after the lapse of some time.

No matter how carefully the vessel be protected from mechanical agitation, the heavy brine which forms at the bottom of the jar

when the salt and the water first come in contact with each other will gradually diffuse into the lighter water above it, until the entire mass of liquid has one uniform composition. This fact of diffusion pure and simple may readily be illustrated by placing a small quantity of a solution of a colored salt, such as potassium bichromate, at the bottom of a bottle of water, and allowing the latter to stand at rest for a day or two.

Even when brine and water are separated from each other by a porous membrane, like bladder or the outer covering of the minute cells of which plants and their roots are composed, this liquid diffusion will still go on, though the phenomenon is then found to be less simple than before.

On interposing the membrane between the brine and the water, phenomena depending upon capillary attraction, or the mechanical power of the membrane to absorb liquids as a sponge absorbs water, and upon chemical affinity of some ingredients of the membrane for those in the liquids, are liable to be manifested simultaneously with the movement of mere diffusion. That is to say, whatever force, whether of adhesion or of affinity, the matter of the membrane can exert upon the substance dissolved in the liquid, comes in to modify the simple diffusive force.

Thus, if a bladder full of brine be fastened to a narrow tube, best of glass, and then be sunk in a jar of water, it will be seen that water passes into the bladder more rapidly than the brine passes out, and so causes a rise of liquid in the narrow gauge tube. By analyzing the water in the jar, it would be found, indeed, that a small quantity of salt has diffused out into the water; but it is apparent, from the position of water in the gauge tube, that in this case water moves in through the membrane much faster than the salt moves out.

Similar results can be obtained by substituting other dense liquids, such as syrup of sugar, for example, for the brine in this experiment. The quantity of water which passes in this way into a saline solution is often very much larger than would be introduced by mere liquid diffusion. It may even amount to several hundred times the weight of the saline matter displaced.

The movement or current of liquid inward (i. e. of the water in the supposed case) is called Endosmose, and the outward movement (of the salt in this case) is called Exosmose. The shorter word Osmose, or Osmosis (impulsion), which includes both the

others, is used as a distinctive term for the phenomena of diffusion through membranes.

Now in the same way that the bladder acts in the experiment, so are the roots of plants supposed to act in the soil. The roots, and all other parts of plants as well, are composed of numberless minute bags or bladders, called cells, which lie close together and constitute the atoms, as it were, of which the tissues of the plant are built up. These cells are generally very small, and even of microscopic size, though in some plants they are large enough to be readily seen and experimented with. Since the liquids within the root-cells are of different composition from the liquids in the soil, the soil liquids are presumed to pass into the root-cells in much the same way that the water flows into the brine in the experiment just now cited.

Some Membranes specially active.

It is to be observed that in all osmotic action very much depends upon the character of the membrane employed. Different kinds of membranes differ widely as to the amount of attraction, whether of adhesion or of affinity, which they exert upon the substances exposed to them. If, for example, the water and the brine in the cited experiment were separated by a membrane of such character that it could exert no action upon either of the liquids, the diffusion would proceed very much in the same way as if no membrane were present. Graham has in fact shown that common salt diffuses into water through a thin sheet of ox-bladder deprived of its outer membrane, at about the same rate as when no membrane is interposed.

On the other hand, it has been proved by experiments of Schacht on the cell membranes of plants having single cells large enough for such observations, that the phenomena of osmose are well marked in the case of these plant membranes. A marine plant called *Caulerpa prolifera*, which has served for this purpose, is said to consist of a single cell that is often a foot in length.

That liquids do actually penetrate into plants through their roots may be shown by watering a plant with some inert colored liquid. I have myself noticed, some years ago, that Indian corn which had been made to sprout in a flower-pot that was watered with milk had white leaves. Here it would seem that the minute particles of solid matter in the milk must have entered the plant, though it is possible that the whiteness of the leaves may have been due to chemical action.

Colloids and Crystalloids.

One other point needs to be mentioned as bearing upon the rapidity of the flow of liquids into plants. The character of the substances in solution, namely, has to be considered, as well as that of the membranes through which the solutions are to flow. It has been found by experiment that different substances diffuse through water even at very different rates. There is one class of bodies of very low diffusive power, called Colloids, which are characterized by a tendency to form jellies with water. And there is another class of comparatively high diffusive power, called Crystalloids, most of which are capable of crystallizing when they assume the solid form.

Among colloids may be named glue (gelatin); the various gums and uncrystallizable albuminous substances, dextrin, pectin, and starch. Precisely those things which are formed within the living plant in abundance have small chance to leak out through the cell walls. Among the crystalloids, on the other hand, are sugar, many vegetable acids, such as citric, tartaric, and oxalic acids, and most of the ordinary salts.

Movements of Plant-Food.

On proceeding to inquire as to the bearings of the foregoing facts upon the theory of the growth of plants, it will be seen that active cells in the rootlets will naturally absorb saline matters from the soil, since the liquids in the root-cells (of a sprouted seed, for example) are of different composition from the liquids in the soil. Each root-cell is, so to say, charged with syrup or with brine as in the supposed experiment.

Diffusion and osmotic action must, moreover, go on from cell to cell, throughout the entire plant, so long as, from any cause, the unlike liquids in the various cells are prevented from coming to a state of equilibrium.

But by virtue of the mere fact of its life perpetual changes are occurring in every part of a growing plant, and there is consequently no lack of causes operating to prevent the attainment of any permanent equilibrium. Almost every change which occurs within the growing plant, no matter whether the alteration depends upon chemical or upon physical action, will tend to perpetuate this incessant diffusion of liquids.

If it be conceived, for example, that a portion of the contents of one cell have combined to form solid starch, or some sluggish col-

loid substance, like albumen or dextrin, an osmotic vacuum, as it were, will be there established, and at the same time a movement of liquids will be started throughout the entire plant to try to fill this void space. A particle of lime coming in contact with oxalic acid to form the insoluble compound oxalate of lime, would produce a similar effect. But changes analogous to these are constantly occurring throughout the entire plant. As the plant grows, new cells and new membranes are formed incessantly, and new quantities of soluble matters are continually brought into the plant.

In the foregoing brief sketch of the mode of introduction of food to plants through their roots, the subject is presented merely as witnessed from the chemist's point of view. It should be said, moreover, that the fact that the contents of the cells of plants are alive or beginning to live tends to make the osmotic movements more active than they would be in dead membrane. The mucilaginous or granulating matter called protoplasm, which fills the interior of the cells undoubtedly works to promote osmose, and physiologists have much to say concerning the manner of its action as viewed and studied by them.[1]

Transpiration of Water.

It is necessary to distinguish carefully between the movements of mere water, by way of osmose, and the movements of plant-food. The evaporation, exhalation, or rather transpiration of water from the leaves of plants, undoubtedly exerts a highly important, and at times a paramount influence, on the osmotic movement of this particular liquid, while it may have nothing or next to nothing to do with the introduction of plant-food proper. In so far as mere water is concerned, it will naturally happen that, as fast as the contents of cells at the extremities of a plant become concentrated through loss of water that escapes as vapor into the air, fresh supplies of water will diffuse into them from the cells next adjacent, and so the movement of water will be transmitted from cell to cell until the store of moisture in the soil outside the plant has been reached. But it is plain at the first glance that this movement of liquid water through the plant is a fact to be considered by itself, and that the exhalation of vapor from foliage cannot be regarded as a prime motor in the matter of supplying saline food to plants. Indeed, we often see vegetation assuming special luxuriance and vigor in atmospheres that are completely saturated with moisture,

[1] Compare, for example, Professor Goodale's Physiological Botany.

as in tropical forests, in some greenhouses, and in the so-called Wardian case. That is to say, growth is most rapid under precisely those conditions where exhalation from the leaves is necessarily small.

Ward's Case.

The Wardian case, named from its inventor, Mr. Ward of London, is a piece of apparatus worthy of attentive consideration. It consists of a close box, provided with a glazed cover and charged with moistened earth for plants to grow in. In its original simplest form the Wardian case was merely a corked bottle half full of moist loam. Commonly it consists of a strong wooden box lined with zinc or lead. At the bottom of this box a porous stratum of gravel or broken earthenware is laid down; immediately upon the gravel a thin layer of turfy loam is placed to serve as subsoil, and finally the box is filled to its brim with loam proper. The loam is well moistened at the start, and a quantity of water is poured into the gravel to serve as a store or reservoir for supplying water continually. After plants have been set out in the earth, a closely fitting glazed cover is placed upon the box, and, if need were, this cover might be firmly cemented to the box. The apparatus thus represents a little world by itself, in which one and the same quantity of water continues to be used over and over again for the support of the plants, while carbonic acid and nitrates are supplied to the plants by the decay of the humus in the earth. The moisture that evaporates from the loam, as well as that which is pumped up and exhaled by the plants, keeps the air in the apparatus saturated with vapor, and the excess of this vapor either condenses upon the inside of the glass cover and thence trickles down upon the earth, or it is reabsorbed directly, as vapor, by the earth, whenever the temperature of the glass is too high to permit of condensation there. Thus it happens that the plants are maintained in an atmosphere saturated with moisture, and are so continually supplied with water that all the evils of capricious and irregular watering are done away with. So too the oxygen that is set free when the plants decompose carbonic acid or water, as will be explained directly, is returned to the air just as it is in the world at large, and this oxygen is thus used over and over again for the oxidation of humus.

Ordinarily as employed in crowded cities where their chief purpose is to protect the plants from soot, dust, grime, and foul air, the cases are not made absolutely air-tight, for it is a matter of convenience

to be able to open them occasionally in order to pluck off dead leaves or to trim or readjust the plants. Thus it happens that small portions of the outer air do gain access to the plants, but it is not necessary that this should occur. One conspicuous merit of the Wardian case is, that, practically speaking, it takes care of itself, both as regards water and air, and the maintenance of a considerable degree of regularity in respect to temperature. But when plants are to be carried long distances on shipboard, as when, for example, Mr. Fortune sent to Europe numerous living specimens of the florist's plants discovered by him in China, the cases are thoroughly closed. After having once been sealed up and placed in such positions that they are properly exposed to sunlight, they are left unopened for almost indefinite periods, sometimes for many months. In smoky London, in particular, these cases were at one time largely used, both within doors, and out of doors in yards and courts and on balconies.

Influence of Capillarity.

It need hardly be said that capillary action within the fibres of the plant is an important aid to liquid impulsion and to the osmotic movements of water in particular. But this capillary or rather conducting movement may be regarded in some sort as if it were outside the cells proper, between them as it were in the interspaces. The significance of it is familiarly shown when children suck up water through a stick of rattan or the stem of a pond lily, and when they make the flexible lily stem serve as a syphon to drain water from a dish. It has been noticed by physiologists that water passes most readily through the fibrous, vascular parts of plants, and it is to be presumed that water drawn in at the roots by way of osmose may be forced through such channels more rapidly than it could pass from cell to cell.

As regards evaporation from the leaves, it may be said yet again, that, although there are frequent times and seasons when the flow of water into and through the plant, to supply the waste of water from the leaves, is exceptionally rapid, this flow has little or nothing to do with the bringing in either of nitrogen or of ash ingredients from the soil for feeding the plant. Transpiration from the leaves, and the movements of water into and through the plant to that end, must be considered by themselves. They are of vast importance, doubtless, but should not be confounded with the normal movements of food and of organized matters downward as well as upward into all parts of the plant, and which likewise appear to be

due for the most part to the action of diffusion and osmose working slowly and constantly through the liquids with which the plant and its cells are charged.

Beside the fact just now alluded to, that plants in greenhouses and glass cases and in tropical forests grow exceptionally well in atmospheres saturated with moisture, we have the common experience that field crops often grow with astonishing rapidity in damp and rainy weather, when the air is so highly charged with moisture that all processes of simple evaporation wellnigh cease, and any loss of water from the leaves by mere evaporation must be decidedly slower than usual.

Transpiration a Physiological Process.

A clear distinction must be made, too, between the idea of mere evaporation, as of water from moist earth, and this special power of "exhalation" or "transpiration," i. e. the throwing off of vapor of water into the air, which is possessed by the leaves of plants, and which goes on incessantly to some extent even when the air which bathes the leaves is already saturated with moisture.

Naturally enough, the escape of aqueous vapor from the leaves of a plant is most rapid in dry, hot, windy weather, especially when the soil as well as the air is warm; but there are experiments which go to show that the exhalation does not entirely cease when the plant is kept in a confined volume of air absolutely saturated with moisture, as in the Wardian case, for example.

Stomata, or Breathing Pores.

According to physiologists, the water transpired from plants escapes for the most part through myriads of minute openings or valves, called Stomata, which exist upon the surface of leaves and of young stems. These openings close in the dark, and they close partially when a leaf wilts, and as a general rule also when a leaf is wet with water. Transpiration is known to be much more rapid in direct sunlight than in darkness, and it is supposed that one reason why this is so is that the stomata or breathing pores are wide open in sunshine, while in the dark they close, and in diffused light they tend to close. For example, Wiesner found that a plant of Indian corn transpired in one hour from 100 square centimetres of surface,

In the dark	97	milligrams of water.
In diffused daylight	114	" " "
In sunlight	785	" " "

But he casts a doubt as to whether the opening of the stomata can account for the whole of these differences, since he found the stomata of young maize plants closed at a time when much water was transpired by these plants.

The main point to be insisted on, however, in this place, is, that the exhalation of water appears not to be essential for the feeding of the plant with nitrogenous matters and ash ingredients.

Plants can live and flourish, as has been said, in atmospheres so highly charged with moisture that exhalation is very feeble. And, on the other hand, no harm is done when exhalation is very rapid, provided the roots are supplied with water enough to make good what is lost from the leaves; otherwise the plant will wilt, and droop, and die. We find in nature plants exposed to the most varied conditions in this regard: there is a wide range between the aquatic plants, which are constantly covered with water, and the cactuses and sagebrush of the rainless deserts.

Yet the amount of water actually exhaled by ordinary agricultural plants is enormous; and it is certain that crops cannot be grown with full luxuriance unless the earth can continually supply to their roots enough water fully to compensate for all that goes off through the leaves. It is plain, not only that water is of the first importance as a means of keeping plants in a succulent juicy condition, so that food may move freely within them and all the necessary physiological processes be favored, but that the exhalation of water acts as a great regulator, which by absorbing and removing heat keeps the plants within fit and proper limits of temperature.

Examples of Transpiration.

There is a familiar illustration of the rapid exhalation of moisture from blades of grass, which has never been sufficiently dwelt upon. When the outer sashes of windows (double windows) are taken down or put up in spring or autumn, or when the sashes of cellar windows are removed, the workmen are apt to leave some of these glazed sashes for a time lying upon the grass about the house. But the moment the cool glass is thus exposed to the exhalation of moisture from the grass, it becomes cloudy and obscured through deposition of the moisture. So, too, if a cold bell glass be placed over a bunch of growing grass, even in the driest season, water enough to trickle from the sides of the jar will be deposited in the course of two or three minutes.

The English observer Watson, who first performed this experi-

ment, was led to conclude from it that an acre of grass land might exhale more than 30 hogsheads of water in a day.

The experiments of Mr. Lawes on various field crops showed that from 150 to 270 grains of water pass through a plant for every grain of solid matter added to the plant; and those of Hellriegel show that rather more than 300 grains are needed, as will be seen directly.

In the old experiments of Hales a single cabbage plant of moderate size exhaled 25 ounces of water in the course of 12 hours, and a sunflower plant 3½ feet high gave off nearly 2 lb. of water in the course of 12 hours on a very warm, dry day. More recent experimenters have observed that grass-sod may give off as much as from 2 to 5 lb. of water for each and every square foot of surface in 24 hours. According to Knop a grass plant in a hot, dry summer's day will exhale its own weight of water. As a rule, young plants give off more water in this way than old ones.

Hellriegel has taken a great deal of trouble to determine how many pounds of water were transpired by various plants which were thoroughly well fed, watered, and cared for at Dahme, a village some miles south of Berlin, in Prussia. For barley, in particular, he found that in the course of its entire life 310 pounds of water were exhaled for every pound of dry matter which was produced in the form of leaves, stem, and fruit, at that particular locality. For other plants, somewhat less carefully studied, he gives the following figures as the amount of water transpired for each pound of dry crop produced:—

	lb.		lb.		lb.
Summer wheat,	338	Horsebeans,	282	Buckwheat,	363
Summer rye,	353	Peas,	273	Summer rape,	329
Oats,	376	Red clover,	310		

The general result of the experiments is evidently that the various crops do not by any means differ so much from one another as to their relative powers of transpiring water as might have been suspected from the differences which they exhibit as to their outward forms or structure. It is of interest to observe in particular that the leguminous plants tested seemed, on the whole, to transpire less water than the cereals for each pound of dry crop produced; and this conclusion was supported by measurements of the transpiratory surfaces of barley, bean, and lupine plants, taken at that particular stage of development of the plants, i. e. that condition of maturity

when their lower leaves had begun to die. It appeared, in fact, that these plants have very much the same amounts of transpiratory surface for every pound of dry substance which they contain. Thus the relations found for barley were 1 : 115 and 1 : 139; for the horsebean, 1 : 131; and for the lupine, 1 : 136.

The figures in the table all refer to perfect plants, that grew under the most favorable conditions possible. But it was noticed that, when the yield of a crop is lessened by any circumstance that hinders growth, the proportion of water transpired to crop produced is always abnormally high.

Apparatus for exhibiting the Force of Osmose.

Ocular evidence of the great force with which the roots of growing plants take in water from the soil may be had by arranging an experiment such as is depicted in the diagram on page 248 of "How Crops Grow." On fastening a pressure gauge to the stump of a vigorous plant, water will be pumped up by the plant from the soil into the gauge, and the mercury in the latter will be forced up into the narrow tube until the column of mercury in that tube is so high that its pressure has become equal to the absorptive force which the roots of the plant are capable of exerting.

By experimenting in this way, Hales found that a grape vine was capable of supporting a column of mercury 32½ inches high,— which would be equal to a column of water 36½ feet high.

Another experimenter, Hofmeister, found that a grape vine supported 29 inches of mercury, a nettle 14 inches, and a bean 6 inches. The flowing of sap in trees when excited by the return of warmth in the spring, long before the appearance of any leaves, as familiarly witnessed in the case of the sugar maple or the "bleeding" of a grape vine that has been cut or injured in the spring, illustrates the same thing precisely. If a glass tube be tied firmly in a vertical position upon a bleeding branch, it is easy to collect a long column of liquid that has been forced up by the action of the roots in direct opposition to the force of gravitation.

Mention may here be made of another piece of apparatus,* devised by the German physiologist, Sachs, to illustrate the osmotic action of the root-cells. A short piece of wide glass tubing is closed at one end with a piece of pig's bladder; it is then filled with a solution of sugar, and closed at the other end with a piece of parchment paper. A caoutchouc cap carrying a narrow bent tube is then

* Figured on page 361 of "How Crops Grow."

tied firmly over the parchment-paper end of the apparatus, and the latter is immersed in water.

The short wide tube represents a root-cell, the outer or bladder-covered wall of which is less penetrable to liquids when exposed to pressure than the inner wall of parchment paper. But the water that passes into the cell by force of osmose soon exerts such a pressure on the parchment paper that a quantity of liquid is forced through this paper into the bent tube, in which it rises to a very considerable height above the surface of the water in the dish. The narrow bent tube may be regarded as representing the stem of a plant, or rather as representing an open capillary channel within a plant stem. This apparatus is readily prepared and is highly efficient. It will sometimes continue to pump water actively during several days.

Solutions of Plant-Food may be highly Dilute.

The subject of osmose and the so-called selective power of plants for inorganic foods will naturally come up again for discussion under the head of manures. For the present, it will be sufficient to have indicated roughly the relation of the plant to the soil, if only the student has been led thereby to reflect upon the manner in which the food of plants is absorbed.

It is to be remembered that the water, or rather the moisture, within the soil, like the water of most of the springs and wells which flow from the soil, is usually by no means highly charged with the substances which have been named above as essential to the growth of vegetation. But the plant has power to gather its food from exceedingly dilute solutions. It can collect phosphoric acid, for example, from waters which contain no more than one part of that substance in ten thousand or twenty thousand parts of the liquid.

It is no unusual thing for the chemist to find substances in the ashes of a plant which he cannot detect by his most delicate experiments either in the soil in which the plant grew or in the water of that soil. It is a familiar fact, for that matter, that an abundance of iodine for use in medicine and in the arts is obtained from the ashes of sea-weeds, though we are wholly incompetent to obtain iodine directly from sea-water, or even to detect its presence there with certainty.

It may be remarked, in passing, that sea-plants well illustrate this capital principle of osmose. The floating sargasso, or gulf-weed, of the middle Atlantic; the kelp of our own coast, — growing often

upon a loose stone or an old mussel shell, from which no nourishment can be derived; the green slimes that flourish upon the surface both of salt and of fresh water, and all the other vegetations which have their being beneath the surface of water, are capital examples of the phenomena in question.

It should be understood, withal, that it is not from actual flowing water alone that plants are nourished. Most plants are supplied with food and with water also in good part from the mere dampness which is noticeable in loam that has been recently disturbed. The hairs upon the rootlets of plants cling to the damp loam and drink in the moisture from it. Young plants are apt to wilt when transplanted because their rootlets cannot immediately come into intimate contact with the earth, and they remain wilted until the rootlets have had time to adhere to the soil.

The significance of the dampness in loam is a matter of common observation. It is exemplified in some sense by an experiment of Sachs. Having grown a bean plant in a pot filled with stiff clay, this experimenter left the plant unwatered until it began to wilt. He then hung the pot in a close vessel full of air that was wellnigh saturated with moisture, but he left the plant proper projecting into the outer air. The wilted leaves soon revived, and the plant remained fresh during the two months devoted to the experiment, although it did not grow.

CHAPTER II.

THE ATMOSPHERE AS A SOURCE OF PLANT-FOOD.

As has been said already, a very large proportion of the dry matter of plants is derived from the air. A seed planted in mere sand may grow into a perfect plant if it be properly watered, and may produce a crop of new seeds, each as large and perfect as the first, although no particle of organic matter, of woody fibre, of starch, of oil, or of any other of the so-called proximate constituents of the plant, be contained in the sand or the water from which the plant has apparently been produced. In one word, there need not be any carbon in the soil, for this most important constituent of plants comes from the air.

Composition of the Air.

Concerning the chemical composition of the atmosphere, it needs to be insisted, first of all, that beside oxygen and nitrogen, together with some vapor of water and a minute trace of ammonia, air always contains a certain small proportion of carbonic acid gas. The average composition of air, by volume, is often stated as follows: —

Oxygen	20.61
Nitrogen	77.95
Carbonic acid	0.04
Aqueous vapor	1.40
	100.00

Since carbonic acid is much heavier than air, 4 volumes of it to 10,000 volumes of air means $\frac{6}{10000}$ parts by weight.

The proportion of carbonic acid in the air varies somewhat in different places, and in any one place at different times, though, taking the whole world through, the amount of the gas is wonderfully uniform.

In countries like the French province Auvergne or the Eifel district on the western bank of the Rhine, where the gas is given off in very large quantities from fissures in the earth, and in the vicinity of active volcanoes, it is but natural that more carbonic acid than the usual proportion should be found in the air. The amount of this gas given off every day from volcanoes in South America is simply enormous. Even in a thick wood where the ground is covered with decaying leaves, twice as much carbonic acid may be found in the air as in that above open fields. Much carbonic acid is, however, evolved from the soil anyway, where it is formed by the oxidation of organic matters; much of it is formed also whenever wood, or coal, or peat is burned, and it is a constant product of the respiration of all kinds of animals.

Experiments made under my own eye in Boston by my assistant, Mr. A. H. Pearson, in the winter of 1869–70, showed an average of 0.0385% by volume of carbonic acid in the air. Angus Smith found from 0.03 to 0.04% in the air of Manchester, England, and 0.0336% in the air of the Scotch hills. Armstrong found 0.031% in the North of England, and Thorpe 0.0295 to 0.031 in sea air. Boussingault in France found from 0.032 to 0.038%; Reiset, 0.0296; Levy, 0.027 to 0.035; and Müntz, 0.0284 to 0.0286. In Germany, Schulze found 0.0292% at Rostock on

the Baltic; Henneberg, 0.032 near Göttingen; Fittbogen, 0.0334 at Dahme; and Farsky, 0.034 in Bohemia. For more southern regions, the estimations of Müntz and Aubin in air from Hayti, Florida, Mexico, Martinique, Patagonia, and Chili give an average of 0.0271%.

The Carbon in Plants is derived from the Carbonic Acid of the Air.

It is this carbonic acid in the air that feeds the plant. In the absence of carbonic acid no green plant can grow. The foliage of young plants cannot even exist for any length of time when exposed to sunlight in air that is totally free from carbonic acid. De Saussure has shown this by enclosing the branches of plants in glass vessels charged with moistened lime, so that the carbonic acid might be absorbed by the lime, and thus be removed from about the leaves.

Decomposition of Carbonic Acid by Foliage.

The history of the discovery that the leaves of plants decompose carbonic acid is not a little curious, and some of the old experiments through which the knowledge of the fact was finally arrived at are highly instructive.

So long ago as 1752 the Swiss naturalist Bonnet observed that green leaves immersed in water and exposed to sunlight give off a gas. Methods of analyzing gases had not at that time been discovered, so that Bonnet's means of studying the phenomenon were limited. He observed, however, that leaves which were immersed in water that had been recently boiled developed no gas, whence he concluded, incorrectly as we now know, that the gas ordinarily observed was nothing more than atmospheric air which had been dissolved by the water, and which collected upon the leaves when the latter were immersed in the water.

In 1771, Priestley, who had devised methods of analyzing gases, turned his attention to the subject. He found that the gas given off by the leaves of plants was sometimes carbonic acid and sometimes oxygen. Sometimes he could not get any gas at all, and, although he noticed that air which had become impure from having been breathed by men and animals could be made better by means of plants, he nevertheless thought that carbonic acid gas was poisonous for vegetation. Percival was the first observer who maintained that carbonic acid taken in at the leaves serves for the support of plants.

A few years after Priestley, in 1779 namely, Ingenhouss proved

that oxygen is given off only when the leaves and water are exposed to sunlight. This was the key to the whole matter. He found also that carbonic acid is given off in the dark, and that those parts of the plant which are not green, such as flowers, roots, and fruit, never give off oxygen, but only carbonic acid. He found, moreover, that in well water the plant evolved more oxygen than in river water. We now know that the well water employed by him probably contained more carbonic acid than the river water.

Our own countryman, Rumford, devoted some time to the study of the question at this period, and his observations are not a little interesting. But it was Senebier who first systematized the matter by showing conclusively, in 1783, that the oxygen thus given off from leaves comes from carbonic acid that was held dissolved in the water in which the leaves were immersed. If there is no carbonic acid in the water, no oxygen will be set free when the mixture of water and leaves is exposed to sunlight. Just so it is with sea-plants that live immersed in water, and so it is with leaves that are in the air. Finally, at the beginning of this century, De Saussure proved that simultaneously with the evolution of oxygen the plant increases in weight through the formation of organic matter.

Nowadays it would usually be found more convenient to study this question with plants or leaves kept in the air, and not in water. The foregoing statement is simply a fragment of history which may serve to indicate how one item of knowledge now familiar was first acquired. There is indeed no one fact relating to vegetable growth which can be more truly called fundamental than this, — that green leaves decompose carbonic acid in sunlight, and that the oxygen of the carbonic acid is set free while the carbon is retained in the plant.

Direct proof that carbonic acid is absorbed from the atmosphere by the leaves of plants is given by an experiment of Boussingault. This chemist thrust the branch of a living vine into one of the orifices of a three-necked glass globe, and fastened it there air-tight. He made a current of air charged with a definite quantity of carbonic acid to flow into one of the orifices of the globe and out of the third orifice. But attached to the third orifice was an apparatus for collecting and weighing all the carbonic acid which was left undecomposed by the vine leaves. He found when the

globe was exposed to sunlight that the foliage within it consumed three quarters of the carbonic acid which was admitted.

Osmose of Gases.

Carbonic acid doubtless enters the leaves of the plant by virtue of the forces of diffusion and osmose, — in a manner analogous to that in which liquids enter at the roots.

It is true of gases even more emphatically than of liquids, that when two or more of them are brought together in a confined space, they instantly begin to commingle, no matter how dissimilar their weights, nor what their relative positions may be. They continue thus to diffuse into one another until a perfectly homogeneous mixture is obtained.

As regards osmose also, it is with gases as with liquids; the rate of their passage through membranes depends only in part upon their relative diffusibilities, since the character and condition of the membrane, and the degree of adhesive force by which it can attract the various gases, come in to modify the mere diffusive force. Other things being equal, the gas which adheres to or is attracted by the membrane most strongly will soonest penetrate the partition.

A remarkable application of this osmotic action was suggested by the English chemist, Graham, several years since. Graham found that the oxygen of the air can be concentrated, as it were, by osmotic filtration. Thin films of caoutchouc, for example, as well as of other membranous substances, though impervious to air, as such, and devoid of porosity in the ordinary sense of the term, are nevertheless capable of absorbing or liquefying the individual gases of which air is composed in such manner that the oxygen and nitrogen absorbed can pass through the membrane, just as ether or naphtha would, and can evaporate again in the form of gas into a vacuum upon the other side of the film.

It appears that in a given time oxygen can pass through a caoutchouc film two and a half times more abundantly than nitrogen, — so that the film may be used as a sieve, so to say, to sift out or exclude as much as one half of the nitrogen contained in ordinary air. Air that has been made to pass through such a film contains between 41 and 42 per cent of oxygen, instead of the 21 per cent which is normally present. A glowing splinter of wood will burst into flame in this concentrated air.

In order to perform the filtration, one side of a thin caoutchouc

bag, kept distended by wire cloth or other proper mechanical appliance, is freely exposed to the outer air, while the atmosphere inside the bag is maintained in a state of partial rarefaction by means of an air-pump. It was thought at one time that air thus concentrated would be useful for smelting metals, but experience showed that it cost more to get the improved air than it was worth.

In the same way, Graham found that carbonic acid can pass through thin films of caoutchouc or other membrane much more rapidly than air or than oxygen. The rapidity of passage of nitrogen being taken as 1,000,

That of oxygen is	2,556
That of atmospheric air	1,149
That of carbonic acid	13,558

Absorption of Gases by Plants.

The leaves of plants, or, more precisely, the membranous coverings of the cells which abut upon the numberless air passages which pervade the plant, are permeable to gases, as other membranes are; they take in the carbonic acid of the air, and the green parts of the plant have power to decompose this carbonic acid in such wise that its carbon is retained by the plant, while the oxygen is allowed to return to the air.

There is no special attraction on the part of the leaves that should draw carbonic acid towards them, except that, as fast as one particle of the gas is decomposed at a given spot in the air, and so withdrawn from the air, another particle diffuses thither to fill the void space, and is naturally decomposed in its turn. As Pfeffer has well said, the movement of carbonic acid in the air towards the leaves of plants is similar in principle to the movement of this gas towards a lump of caustic potash that has been left exposed to the air. In a very short time this potash will absorb a great deal of carbonic acid, simply because, as fast as one particle of the gas is absorbed, another particle moves into its place to be in its turn held fast by the alkali.

In this way it happens that carbonic acid is continually taken in by plants out of the atmosphere, and transformed into the various components of vegetation.

By force of the law of the diffusion of gases, to say nothing of the stirring action of winds and other currents of air, new portions of carbonic acid are incessantly brought to the plant from without.

Fixation of Carbon by Plants.

Very little is known as to the precise manner in which the decomposition of carbonic acid is effected within the plant. It is known, indeed, that the decomposition is in some way intimately connected with the green chlorophyl grains to which the color of the leaves is due; and it is known that light is necessary in order that the decomposition may be brought about. But little has been learned as yet as to the details of the process of decomposition.

Boussingault has suggested the hypothesis, that carbonic acid and water may possibly be decomposed and deoxidized simultaneously, in accordance with the formula,

$$CO_2 + H_2O = COH_2 + O_2.$$

Or, if each of these symbols be multiplied by 12, then $C_{12}H_{24}O_{12}$. And if from this formula one molecule of water be subtracted there will be left $C_{12}H_{22}O_{11}$, which represents the actual composition of cane sugar and gum. If two molecules of water be removed, the formula of starch, cellulose, and their isomers, is obtained, viz. $C_{12}H_{20}O_{10}$.

All this is, of course, mere speculation. It is equivalent to saying that one way at least may be conceived of in which the decomposition might occur.

It is interesting to observe, however, that the equation as above written consists with the observed fact that the volume of oxygen set free by the plant is very nearly equal to that of the carbonic acid decomposed. It is known, also, that in the great majority of plants more or less starch is to be found in the chlorophyl grains, and it has been noticed that the starch thus enclosed in the chlorophyl is usually the first visible product that is formed when carbonic acid is decomposed by leaves.

The starch thus formed is continually dissolved and carried out from the leaves to be used in building up new leaves and other parts of the plant, and it is only the excess of it, so to say, that can be observed at any one moment. Microscopists have repeatedly noticed that starch disappears completely from the chlorophyl grains, both in the dark and when the leaves are exposed to air that contains no carbonic acid, but that new quantities of it are speedily produced when the plant is again exposed to light and to normal air. There are exceptional cases, however, where, instead of starch, other compounds are formed in the chlorophyl grains when carbonic acid is furnished to leaves that have previously been

deprived of it. Sometimes oil is formed, sometimes mannite, and sometimes grape sugar (or an isomer) as in the onion. The prominent facts are, however, that the green chlorophyl grains assimilate a part of the carbonic acid of the air, and that the assimilated matter is digested by the plant cells and converted into the various components of the plant, somewhat in the same way that the food eaten by an animal is changed to bone and muscle by the stomach and the blood.

Some Plants feed upon Organic Matter.

The foregoing statement refers, of course, to the ordinary plants of cultivation, that bear flowers and seeds. Mushrooms, toadstools, and the other fungi, assimilate food in a different way. They have no power to produce organic matter out of carbonic acid and water; but, like animals, they are forced to feed upon vegetable or animal matters, or their remains, which they find ready formed. Not only do we see the larger fungi growing freely upon decaying matters, but experimenters are accustomed to cultivate the smaller microscopic kinds in solutions that contain some soluble compound of carbon, such as sugar, or a tartrate, or an acetate, beside ash ingredients, and a nitrogen compound.

Unlike animals, which destroy organized matters, plants of the higher orders may be regarded as agents for accumulating power from inorganic materials, and for storing up power for future use in the form of food and fuel. In this sense, the prime object of agriculture is to collect, for purposes of human aggrandizement, as much as may be possible of the energy which comes to the world in the form of light and heat from the sun. Plants work constantly to counteract destructive agencies, such as combustion and animal life, which are continually resolving fuel and food into inorganic materials. All the wood, coal, and peat, and all the food in the world, have been formed in the last analysis from the action of sunlight on the chlorophyl grains in the leaves of plants, working to decompose the carbonic acid of the air. Of course, every pound of carbon thus taken from the air and converted into vegetable matter represents an increase in the available energy of the world equal to the force which can be generated on burning this amount of carbon.

Kind of Light needed for the Fixation of Carbon.

With regard to the agency of light in the matter of decomposing carbonic acid, it is interesting to observe that the action is not due to the actinic or chemical rays, whose power of effecting chemical

decomposition is familiarly seen in the processes of photography, and in the myriad instances of the "fading" of colors by sunlight. The actinic rays doubtless play an important part in the elaboration of some of the components of the plant, but they have very little if any influence in the process of decomposing carbonic acid. For this fundamental operation intense sunlight is essential.

Several observers have found that the decomposition of carbonic acid by leaves is most rapid in the yellow rays of the solar spectrum, and that in passing from the yellow part of the spectrum towards either of its ends the decomposition diminishes. Pfeffer has drawn up the following table to illustrate the rate of diminution, the maximum decomposition in the brightest yellow being taken at 100.

Red	25.4	Blue	22.1
Orange	63.0	Indigo	13.5
Yellow	100.0	Violet	7.1
Green	37.2		

In the invisible heat rays that lie beyond the violet there was no decomposition at all. When the results above given are represented graphically, the curve resembles very nearly one which represents the brightness of the spectrum as it appears to the eye.

Plants need Abundant Light.

All experience teaches that the amount of carbonic acid decomposed at a given time depends on the intensity of the light; and, in general, it is known that the prosperity of plants depends largely upon the amount of light they receive. Indeed, the importance of abundant light, as distinguished from heat, for the rapid growth of plants can hardly be overrated.

The marvellously rapid advance of vegetation which, as travellers report, is to be seen in Norway and Sweden in spite of the late spring and short and by no means hot summer of that northern clime, is to be explained by a reference to the very short nights, or rather to the long-continued daylight, to which vegetation is there exposed.

The farther north grain is grown, so much the shorter is the term of its vegetation. Barley ripens 20 days earlier at Alten in 70° of north latitude, where on the average of years the mean summer temperature is only 54° F., than it does at Christiania in latitude 60°, where the mean summer temperature is 60°; and yet the plants are as well developed in the one place as in the other. Curiously

enough, this power of ripening speedily becomes hereditary in the course of some generations, so that plants springing from seeds that have been brought from the far north to more southern localities grow as fast, at first, or almost as fast, as they would have grown at home.

It is because of the abundant light of the arctic summer that rye and wheat can be grown in Siberia as far north as latitude 65° or 66°, where, because of the long, cold winter, the mean annual temperature is no higher than 15° F., and where the ground is so nearly perpetually frozen that the soil never melts to a greater depth than two or three feet.

Plants grown by Artificial Light.

It was disputed at one time whether the normal processes of growth can be carried on at all in artificial light, and the question was complicated by results such as those obtained long since by Mr. Ward (the inventor of the closed case), who found that crocuses at least may be grown by gas-light. But here, of course, the motive force had been stored up in the crocus bulb the year before. In a similar category must be placed an old experiment of the botanist De Candolle. By confining a sensitive plant in a dark place in the day-time, he found that the leaves soon closed; but on lighting the chamber with many lamps, they opened again.

The general conclusion seems, however, to have been, that the light of oil lamps and gas burners is not strong enough to enable the leaves of plants to decompose carbonic acid; though the experiments of Hervé-Mangon in France and of Siemens in England show clearly that the growth of many plants is possible in strong artificial light, such as that of the electric arc, much in the same way that it is possible in the dim light of a forest, or in any dense shade. There is no longer any reason to doubt that many kinds of plants may be grown by artificial light, especially such plants as require but little light naturally.

Some Plants grow in Cool Weather.

It hardly needs to be said that a certain degree of cold checks the power of leaves to decompose carbonic acid. Cloez found that at 39° F. certain water plants studied by him no longer evolved oxygen, and that none was given off until the temperature had reached 59° F. From this point the evolution increased until 86° had been reached, at which point it was at its maximum. When the temperature was allowed to fall, the decomposition of carbonic

acid diminished, until at 50° it ceased entirely. On the other hand, Boussingault found that larch needles decompose carbonic acid at temperatures ranging from 33° to 36° F., and it is probable that many kinds of plants that continue to grow in cool weather can assimilate carbonic acid perhaps even more readily than the larch.

Heinrich observed that Hottonia leaves can still decompose carbonic acid regularly at a temperature of 42° F., but hardly to an appreciable extent at 37°. The highest temperature at which these leaves still evolve oxygen lies between 122° and 133° F., and the best action occurs at about 88° F. In the case of Vallisneria, Sachs observed a slow evolution of oxygen at 50° F., but none at 45°. Indian corn and Mimosa pudica, he says, first begin to decompose carbonic acid at temperatures above 59° F.

Plants give off Carbonic Acid in the Dark.

It is to be observed that in the entire absence of light plants exhale no oxygen but only carbonic acid. So far from the plants being able to decompose carbonic acid in the dark, this gas is then not only produced within the plant, by the action of oxygen upon some portion of it, but is actually given off from the plant into the air. This point will be referred to again directly, when the relations of the plant to oxygen are treated of.

In testing the significance of light, Boussingault found that a bean which weighed 0.922 grm. grew in 25 days, under normal conditions, to a plant which weighed when dry 1.293 grm. The increase of 0.371 grm. consisted of 0.1926 grm. carbon, 0.1591 grm. oxygen, and 0.02 grm. hydrogen. But another bean grown at the same time, under like conditions excepting that light was excluded from it, diminished in weight from 0.926 to 0.566 grm. This loss of 0.36 grm. consisted of 0.1598 grm. carbon, 0.1766 grm. oxygen, and 0.0232 grm. hydrogen.

Composition of the Air in Plants.

The importance of light in enabling the plant to decompose carbonic acid has been shown by still another method of research, somewhat different from either of those above alluded to. It has been shown, namely, by comparing air taken from the interior of plants which had been kept in the dark with air taken from inside similar plants after exposure to sunlight.

To collect the air, the plants under examination were placed in glass vessels full of water, from which water all traces of air had been expelled by boiling. The vessels were then put into commu-

nication with a vacuum, in such wise that the air in the interior of the plants escaped therefrom into the vacuum, where it was collected for analysis. Separate pairs of bundles of the plants were kept in the dark for some time; one of the bundles was then exposed to sunlight for about 20 minutes, and both bundles were then subjected to the process of exhaustion which freed them from air.

Oat Plants kept in	Date.	The Gas taken from the Plants contained Percent of		
		Nitrogen.	Oxygen.	Carbonic Acid.
The dark,	31 July	77.08	3.75	19.17
In sunlight,	"	68.69	24.93	6.38
The dark,	2 Aug.	68.28	10.21	21.51
In sunlight,	"	67.86	25.95	6.89
The dark,	"	76.87	8.14	14.99
In sunlight,	"	69.43	27.17	3.40

These experiments, which were made by Messrs. Lawes, Gilbert, and Pugh, show, that atmospheric air does gain access to the interior of the plant; that, in the dark, the oxygen of the air acts upon portions of the plant to form carbonic acid; and that in sunlight carbonic acid is decomposed by the plant, and oxygen set free.

It is noticeable in the table, that the proportion of oxygen was in one instance reduced, in the dark, from the normal 21% to 4% of the volume of the air. Evidently most of the oxygen had been used up in combining with some carbonaceous portion of the plant.

Importance of Oxygen as Plant-Food.

It is important to recognize clearly that this action of oxygen upon the growing plant is a matter of the first importance. Misconceptions as to this point are apt to arise in the minds of students, because of the fact that the subject is so complicated with that of carbonic acid that writers often mention it as if it were subordinate, or even trivial. This is not the case. To begin with, the amount of oxygen contained in vegetable matters is really very large. Boussingault weighed and analyzed all the crops that were produced in the courses of various rotations practised on his farm in Alsatia, and he found, for example, that the useful products harvested from a hectare (= 2.5 acres) of land during a six years' rotation of potatoes, wheat, clover, wheat and turnips, peas, and rye, weighed altogether 46,566 kilograms (1 kilo. = 2.2 lb.) in the fresh or air-dried condition, and that there was contained in all these products:[1]—

[1] Mémoires de l'Académie de France, 1842, xviii. 383.

10950	9405	1269	354	1353
kilos of carbon.	kilos of oxygen.	kilos of hydrogen.	kilos of nitrogen.	kilos of ashes.

Furthermore, it may be said of plants as truly as it can be said of animals, that all the processes of life go on within them by day and by night by virtue of forces that are developed by the oxidation of organic matter. In the same way that animals die when placed in air which contains no oxygen, so do green plants, except that the latter can (in the light) get enough oxygen to prolong their existence somewhat, by decomposing the carbonic acid which is formed within them. Some plants of the lower orders, such as the yeast plant, for example, are exceptions to the rule only in so far as they are able to get the necessary oxygen from the organic substances on which they feed. It has been noticed even as regards mushrooms and lichens, that they absorb oxygen freely from the air for purposes of respiration, and evolve carbonic acid.

Large Quantities of Oxygen are consumed by Germinating Seeds, and by Roots, Buds, Flowers, and Fruit.

Oxygen is essential, from the beginning, for the process of germination. Seeds do not germinate in the absence of oxygen. Even a seed that had sprouted would soon wither and perish if it were wholly deprived of oxygen. It has been noticed, however, that, while in pure oxygen gas germination is no quicker than in ordinary air, the process succeeds in air that contains from $\frac{1}{8}$ to $\frac{1}{16}$ oxygen as well as if the air contained the normal proportion ($\frac{1}{5}$) of oxygen. Germination is still possible in air that contains no more than $\frac{1}{32}$ of oxygen, though in this case the process is very much retarded, and there is a risk of producing weak and unhealthy plants. In sowing seeds care has to be taken not to bury them too deeply, lest they should be too completely cut off from the oxygen of the air.

The opening buds of trees also absorb oxygen from the air in considerable quantity, as was shown long ago by De Saussure, and in an atmosphere free from oxygen such buds soon decay. Some oxygen is taken up by the roots of plants also, and the presence of oxygen is essential for the life and activity of roots, though plants differ very much as to the amount of oxygen needed for this particular purpose. Most agricultural plants will not prosper unless the soil in which they stand contains numerous pores, which are filled more or less completely with air. Such plants are apt to suffer whenever the soil becomes water-soaked, and thereby freed from

air. But many water plants have access only to the oxygen which is held in solution by the water which surrounds them. Various rushes also, and other swamp plants, grow freely in soils so saturated with water that very little air can come to their roots beside that which is dissolved in the water. Indeed, some swamp and marsh plants can withstand water which has been exposed to reducing agencies, and deprived of most of the oxygen that would naturally be dissolved in it. But it is nevertheless true, generally speaking, that the roots of plants need oxygen in order that they may live. Most plants speedily die when their roots are enveloped with an atmosphere that contains nothing but carbonic acid gas and nitrogen. Roots appear to be able to live, however, when immersed even in pure oxygen; and it has been noticed that while they take up oxygen they give out carbonic acid, though the amount of the latter exhaled is less than the quantity of oxygen absorbed.

One objection to the establishment of too large an amount of asphaltum pavement in parks appears to be that the asphalt may hinder the tree roots from gaining ready access to oxygen, though the vapors or liquids that come from the asphalt are likely to be directly hurtful in themselves.

Even in water culture it has been noticed that the roots grow better when air is made to bubble through the liquid, and that the formation of sulphide of iron which ordinarily occurs there may thus be wholly prevented.

Oxygen is taken up by ripening fruit also, and particularly by flowers, a corresponding quantity of carbonic acid being meanwhile produced, and even given off from those parts of the plants which have absorbed much oxygen.

Plants generate Heat.

It is notorious that in all chemical processes of oxidation, such as these, more or less heat is evolved, and it is found as a matter of fact that heat is actually generated by growing plants. It often happens that snow falling upon growing grass in early autumn or late spring may be seen to melt away rapidly, and continue to do so for a considerable period of time, while it may remain lying intact for a long while upon the adjacent ploughed fields and roadways. So too, when a leafy plant is placed in a confined volume of air that has been saturated with moisture, it will continue to throw off vapor of water from its leaves into that air, while the

temperature of the air, and consequently its capacity for holding the vapor of water, will be increased by the heat which the plant emits.

Indeed, the mere act of evaporating water from the leaves into ordinary air must often depend in some part on warmth that has been generated within the plant by the chemical reactions which occur there. It is because of this chemical action that the temperature of plants is usually somewhat higher than that of the surrounding air, and that from plants, as from animals, aqueous vapor is constantly escaping in the form of insensible perspiration.

At the moment of flowering, so much heat is developed by plants that it is often easy to measure it with the thermometer. Garreau observed that a spike of the flowers of Arum italicum absorbed 28½ times its own bulk of oxygen in one hour, and that its temperature was 15° F. higher than that of the surrounding air.

Dutrochet noticed an increase of temperature of 11 or 12° C. caused by Arum maculatum in the act of blossoming, and Poisson reports an increase of about 10° C. above the temperature of the room when Dioon edule flowered.

Fruits, such as apples, pears, and oranges, absorb large quantities of oxygen, and give off corresponding amounts of carbonic acid, not only in ripening, but even when they are fully ripe, as the term is; and this process of oxidation is manifestly necessary, both for the maturation and for the life of the fruit. So, too, with seeds. A seed that has been made to germinate in the dark, far from showing any increase of weight as the sprout grows, actually decreases in weight steadily, from loss of substance through oxidation. Carbonic acid is given off from it, as was just now stated.

Oxygen seems, in short, to act for the most part upon matter which is already organized in the plant. It takes conspicuous part in the changes by which this matter is converted into other organized forms; as when portions of the plant are converted into flowers and fruit, or the matter of the germinating seed is made to nourish the young sprout. These are processes, it should be noticed, which go forward at the expense of the plant itself, both by night and by day. It is only in the green leaves and stalks of plants, not in their seeds and flowers, that the crude, unorganized materials taken in from the air and the soil are elaborated into new compounds. The flowers and fruits of plants correspond, in fact, to the eggs and the young of animals in that they are nourished by the parent plant.

That oxygen has important functions to perform at all times might justly be inferred from the well-known fact that in the dark plants slowly but incessantly exhale carbonic acid derived from the oxidation of some part of them. From all that is known of this exhalation of carbonic acid, it would appear that the gas is really produced continually within the plant, both in the light and in darkness, by the action of oxygen upon certain components of the plant. But in the light the carbonic acid thus formed is decomposed again in due course by the green chlorophyl grains, so that it is never actually exhaled. Hence it is only in the dark that the effects of the oxidizing action can readily be perceived.

It has been found that plants exposed to the dull light of a cloudy day will sometimes exhale carbonic acid, and at other times oxygen, according to the intensity of the light, and the age, or rather the state of development, of the plant. But in any event the quantity of oxygen absorbed by plants, as measured by the amount of carbonic acid given off in the dark, is vastly less than the quantity of carbonic acid fixed by the plant during the day.

From the experiments of Corenwinder, it appears that a plant will absorb and decompose as much carbonic acid in 15 or 20 minutes of direct sunlight as it would exhale in a whole night.

Boussingault found, as the average of several experiments, that while a square yard of oleander leaves exposed to sunlight decomposed a quart of carbonic acid in an hour, the same amount of leaf surface exhaled no more than six hundredths of a quart of carbonic acid in the dark.

It is to be remarked, that red, or dark, or purple leaves, as of the purple beech, for example, or colored algæ, decompose carbonic acid readily enough, for such leaves contain chlorophyl grains that are masked or concealed by the dominant color.

The relations of oxygen to the soil need not be considered here, since they can be discussed much more conveniently further on, in connection with the subject of tillage.

Free Nitrogen Gas is not Food for Plants.

Of free nitrogen, as it exists in the air, it may be said curtly, there is no good evidence that any of it can be assimilated by agricultural plants. It seems surprising, at first sight, that this statement should be true, so accustomed are we to exhibitions of the prodigality of Nature. It seems strange indeed that plants should

be bathed with an atmosphere containing nearly 80 per cent of nitrogen and have no power to use any of it.

Much thought and labor have been expended by chemists in trying to prove the contrary. But all the trustworthy experiments which have been made hitherto, and there is no lack of them, point plainly to the conclusion that free nitrogen cannot be assimilated by the higher orders of plants.

Without going into any discussion of the extended researches which have been made upon this subject, it will be sufficient to describe briefly one of the methods of research employed by the distinguished French chemist Boussingault. He put into a number of glass carboys artificial soils made of washed and roasted pumice-stone admixed with the ashes of stable manure. He moistened the soils with pure water, and sowed in them the seeds of various kinds of plants. After the seeds had germinated he inverted a small flask of carbonic acid gas in the mouth of the carboy, and fixed it there air-tight, the idea being to supply in this way the carbon needed for the growth of the plants. The apparatus was then set into the soil of a garden to keep it cool, and left to itself for several months. It was a Ward's case, except that the soil in which the seeds were sown contained neither nitrogen nor carbon.

Finally, the plants obtained were carefully analyzed for nitrogen; and, in the same way, an equal number of the seeds were analyzed, i. e. a number of seeds similar to that from which the plants had grown.

As the mean of many experiments, it appeared that the total amount of nitrogen in the dwarf plants obtained was a little less than that contained in the seeds from which they grew. Absolutely no nitrogen was gained from the air.

But plants have great need of nitrogen, and if any of that element had been put into the carboy in assimilable form (as a nitrate or an ammonium salt, for example) it would have been quickly taken in by the plants and have been detected when the plants were analyzed.

It is always hard to prove a negative; but in the present case so large a mass of adverse evidence has been accumulated that there would seem to be no longer any point left open for discussion, were it not for the recent discovery that certain microscopic organisms in the soil do actually fix free nitrogen from the air, as will be described under the head of Vegetable Mould. Although these microscopic

fungi differ widely from most agricultural plants, their action suggests anew the inquiry whether the cells of some special kinds of cultivated plants may not perhaps be able to fix small quantities of free nitrogen in an analogous way. As has been said, there is much evidence which militates against this supposition.

An interesting account of several standard experiments made to test the significance of nitrogen gas as plant-food will be found in Johnson's "How Crops Feed," pp. 28–33. It is to be remarked that the investigation is beset with several palpable sources of error, which need to be specially guarded against.

1. The soil employed must be wholly freed from nitrogenous matters, and no dust from the air should be allowed to gain access either to the soil or to the plants.

2. There are some small traces of ammonia and of nitrates in the air whose influence must be avoided.

3. It is extremely difficult, if not impossible, to prepare water that is wholly free from ammonia; and in any method of experimentation, where much air or much water is used, the influence of the ammoniacal impurity tends to become cumulative, and greatly to increase the risk that it may vitiate the experiment.

4. Probably most plants, if not all plants, can on occasion obtain a little nitrogenous food from insects that die upon them, and it is extremely probable that lupines (which are both hairy and sticky), and perhaps clover also, may really be carnivorous enough to profit to an appreciable extent from the nitrogen of insects which they may capture.

From all of which it appears that that method of experimenting must be best which most fully excludes the various sources of error. Regarded in this light, the arrangement of Boussingault's apparatus will be seen to display an amount of common sense which distinctly simulates genius.

Leaves may absorb Ammonia Gas.

There can be no doubt that the carbonate of ammonia which exists in minute proportion as a gas in the air is absorbed by plants. But the amount of this atmospheric ammonia is so small that it can have little direct effect upon vegetation. When collected and concentrated by dew or rain, and so brought down to the roots of the plant, it acquires a certain small geological importance, as will be shown hereafter.

Many experiments have proved that this atmospheric ammonia

has no appreciable influence upon the growth of plants that are protected from contact with dew and rain; although it has been found that the vapor either of ammonia or of carbonate of ammonia, added artificially to the air, greatly promotes the growth of plants that are standing in that air, whence it appears that the only trouble with the atmospheric ammonia is its extreme dilution. If there were but more of it, it would be valuable.

Very striking results are said to have been obtained by placing lumps of solid carbonate of ammonia upon the hot-water pipes of a conservatory, so that the ammonium salt could evaporate into the apartment in the proportion of from 2 to 4 parts for every 10,000 parts by weight of air.

It does not appear that light has any influence upon the absorption of such atmospheric ammonia. It is likely, however, as Mulder has suggested, that the ammonia enters into chemical combination with the acids with which the juices of growing plants are almost always charged. Even before the elaborate experiments of Darwin showed that various fly-catching plants actually digest and feed upon the flesh of their prey, it might justly have been concluded that the pitcher-plant can gain nitrogenous food from the insects that are drowned in its reservoir of water. For even if the insects were not consumed directly by the plant, they would decay in the water, and ammonia would thus be formed, and by the absorption of this ammonia the plant would profit.

Absorption of Aqueous Vapor by the Leaves of Plants.

It has been not a little disputed whether ordinary plants ever absorb directly for purposes of growth any of the vapor of water that exists in the air. That they can do so, however, on occasion, at least in some cases, is familiarly shown by branches, or even logs, of willow or poplar, that have been detached from the parent stem or stump before the growing season, and left disconnected in the air. Such branches or boughs die hard. They may indeed live for several months, and continue to form occasional new leaves after all connection with the soil has ceased, and no liquid water has come to them. It is plain in this case that the vapor of water in the air must play an important part in keeping up the movement of sap by which the leaves upon these detached boughs are nourished. Such observations as these seem at first sight to be little consistent with the well-known fact that aqueous vapor is ordinarily given off continually from the leaves of growing plants,

under all circumstances, and even when the air that surrounds them is saturated with moisture. But since neither of the facts can be discredited, the chief point to be insisted upon is that the quantity of water ordinarily absorbed by leaves must be very small. On the other hand, there can be no question that the amount of water taken in by roots is very large, and of overwhelming importance for the growth of crops.

Contrary to the commonly received opinion, it does not appear that the foliage of ordinary plants usually absorbs much, if any, of the liquid water that falls upon it as rain, or that is deposited as dew; although it is true, as has been shown by careful experiments, that small quantities of liquid water can be absorbed by leaves that are immersed in it, and brought into intimate contact with it. Mariotte taught, toward the close of the seventeenth century, that when wilted leafy twigs are placed in water with their tips downward so that the part where the twig has been cut or broken shall be left in the air, the leaves will gradually swell to their original condition. So too, the rapidity with which plants that stand badly wilted in the field in hot weather are seen to revive when they are rained upon, would appear to indicate that some of the rain water must be absorbed directly by the leaves; for, on the supposition that, when leaves are cooled by rain, the moisture previously lost from them by excessive exhalation can be made good by water that is pumped into the plant by the roots, it would seem as if much more time would be required in order that water may pass from the roots to the leaves than does in fact elapse during the actual resuscitation.

But, upon the other hand, it will be noticed, when the leaves and stalks of plants are covered with particles of rain or dew, that the liquid is usually prevented from coming into intimate contact with the absorbent surfaces of the plant, either by the waxy coating natural to the leaf or stem, or by the numberless little hairs which grow upon it.

The foregoing statements all refer to ordinary leafy plants, but, as regards mosses and lichens, it is known that they can absorb moisture freely from damp air, and become soft and flexible; and that contrariwise they are made harsh and brittle by hot dry air. After all has been said, it may be asserted without any hesitancy that the roots of plants are the true absorbents of water, and that practically speaking almost the whole of the water consumed by

plants is taken in through the roots from the soil. Indeed, it is a matter of familiar experience, that enormous quantities of water are taken in at the roots of plants and given off again into the air through the leaves. A small part of the water thus taken in is undoubtedly assimilated by the plant, and made to combine chemically with carbon to form vegetable compounds. Moreover, it is to the water thus taken in, and, so to say, fixed, that we must look for the source of the hydrogen which is an essential component of every organized substance. Some water, moreover, is always held mechanically in the pores of the plant.

As might be anticipated, all the experiments go to show that the amount of vapor given off by plants may vary greatly, accordingly as the external air and the soil also are hot or cold, moist or dry. Transpiration is peculiarly rapid in warm, dry air. It is much more active in direct sunlight than in the shade, but it does not wholly cease even at night. Evergreen plants are said to transpire less than other kinds. In the intense heats of summer, plants wilt because moisture is given off by their leaves faster than the roots can supply moisture; but the revival of the wilted plants by a shower of rain appears to be due chiefly to the facts, that evaporation is checked when the plants are cooled by the rain water, and that the air around the leaves becomes partially saturated with moisture.

Relation of the Soil to Heat.

There is little need of insisting that abundant heat is indispensable for the growth of crops. It is a familiar fact that the distribution of each particular kind of plant upon the earth's surface is determined primarily by climate. In the words of De Saussure, "We deceive ourselves exceedingly when we imagine that the fertility of any district depends wholly on the nature of the soil, because abundance and scarcity in crops arise principally from the degree of heat and humidity in the air." "I have seen," he says, "in Sicily and Calabria, arid and uncultivated rocks and gravel, such as in Switzerland would have been altogether barren, which there produced more vigorous plants than are to be seen on the richest and best cultivated lands among the Helvetic mountains."

It is true, however, after fully allowing for the general climate of the locality, that the temperature of the soil of any particular field may be subject to a great variety of circumstances. It will be influenced not only by the quantity, quality, and direction of the

sun's rays which fall upon it, but by the temperature and amount of the air, the rain, and the ground water which come in contact with it; by the amount of heat developed within it through oxidation of the organic or other oxidizable substances which it contains; by loss of heat through evaporation of water; by the capacity of the soil itself, for absorbing and retaining, or for radiating and reflecting heat, and doubtless by other conditions, such, for example, as those dependent upon the presence or absence of vegetation, and of microscopic organisms.

Position of the Soil as regards Sunlight.

The importance of "aspect" or "exposure" need hardly be dwelt upon. Everybody recognizes the significance of the "lay of the land." In popular estimation, the morning sun is held to be specially auspicious for the growth of plants, and no doubt justly. In the words of an English writer (Marshall): "A southeastern aspect collects a greater quantity of heat, enjoys a longer day, than any other. It is noon before a western aspect reflects a ray. In the morning it will frequently remain dewy and cold several hours after vegetation has been roused against an eastern inclination. The afternoon sun is no doubt more intense on the west than on the east side of a hill; but its duration is short. In the afternoon the air is everywhere warm; and a regular supply of warmth appears to be more genial to vegetation than a great and sudden transition from heat to cold. The coolness of evening comes on, and vegetation is probably checked, as soon, or nearly as soon, in all aspects. Hence we may fairly conclude that the southeastern aspect enjoys more vegetative hours, and receives a more regular supply of heat, than any other."

Mr. Mitchell also speaks in terms of enthusiasm of "the gentle slope south or eastward which shall catch the first beams of the morning, and the first warmth of every recurring spring." He says: "In a mere economic point of view, such slope is commended in every northern latitude by the best of agricultural reasons. In all temperate zones two hours of morning are worth three of the afternoon. I do not know of a writer upon husbandry who does not affirm this choice, with respect to all temperate regions. If this be true of European countries, it must be doubly true of New England, where the most trying winds drive from the northwest."

In Italy, the irrigated mowing-fields are made to slope from north to south, whenever practicable, while the irrigating and drainage

ditches run across them from east to west. It is on high mountains, however, that the significance of exposure is best seen. It is known, for example, that on the southerly sides of some of the Alps both vegetation in general, and the cultivation of grain in particular, reach higher elevations than on the northerly sides. While rye and barley are grown at a height of 4,000 feet above the sea level in Swiss valleys that face to the north, they attain to 5,000 feet in valleys that are exposed to the south. In Lapland also, and in Spitzbergen, the southern sides of hills are said to be sometimes covered with vegetation, while the northern slopes are buried in perpetual snow.

The question of aspect has been studied methodically by Kerner, and afterwards by Wollny at Munich, who threw up for his experiments an artificial mound, in the soil of which were planted numerous thermometers. These instruments were sunk six inches deep in the sandy soil, which contained a little humus and which lay sloping at an angle of 15°. It appeared plainly that the maximum temperature of the soil from November to April was on the slope that faced southwest; in the summer, it was on the southeast slope; at the beginning of autumn, on the south; and in late autumn, on the southwest. So too, in beds running in various directions thermometers sunk six inches deep showed in summer that the southerly sides were warmest; next came the flat land, then the east and west sides of the beds, while the northerly slopes were coldest. Hence crops cultivated in beds running from north to south will be more equably warmed than if the beds ran east and west, although the latter may sometimes attain a higher temperature by day. It was noticed, however, that flat cultivation insured a more equable temperature than any of the beds, and indeed a higher average temperature than the best of them.

Wollny concludes that, of the several exposures, the south, southwest, and southeast are the warmest; that east and west come next in order, then northeast and northwest, and last north, which shows the lowest temperature of all. Generally speaking, variations of temperature in the soil are widest on southerly exposures, and they are smaller in proportion as the slope approaches towards the north.

The steepness of a slope is not without its influence. The sun's rays will strike most powerfully upon a hillside inclined towards the south at an angle of 25° or 30°. In northern countries a de-

clivity thus exposed to the sun, and sheltered against cold winds, may enjoy a local climate as different from that of the surrounding region as if the field had been transported through several degrees of latitude.

In the vicinity of Boston farmers choose the southern slopes of hills, even where the soil seems to be poor and gravelly, for growing early vegetables. So it is with regard to the placing of dwelling-houses, as well as with the planting of crops. As the city expands, many houses are built upon the "right sides" of the suburban hills long before any one thinks of erecting buildings upon the "wrong side."

Reflected Heat.

The significance of reflected heat is illustrated by the common European custom of ripening delicate fruits upon the sunny sides of walls. Pears and plums are ripened in this way in the north of England every year, even in the least favorable seasons, in a climate which even a New Englander would call horrible.

Absorption and Radiation of Heat. — Significance of Color.

The capacity of walls and soils for absorbing and radiating heat is another item of importance; and with this point the color of the soil is more or less intimately connected. As a general rule, it may be said that dark-colored soils absorb heat most rapidly, and radiate it most freely.

The experiments of Franklin are familiar, in which bits of cloth of different colors were laid on the surface of snow. After a while it was found that the snow had melted most beneath the darkest cloths. Other things being equal, it is the frozen ridges of black soil in the ploughed fields which are first seen to emerge from beneath the snow in early spring. Light-colored soils can be made warm in this sense by strewing dark-colored substances upon them.

There is an old experiment of Professor Lampadius, of Freiberg, who was able to ripen melons in that inclement town by covering the soil with coal-dust to the depth of about an inch. So, too, Hanney leached a quantity of soot with water to remove its fertilizing constituents, and strewed it in alternate stripes upon half the soil of a potato field. Before the vines had grown large enough to shade the ground, the temperature of the soil on sunny days, as the mean of ten observations, was:—

At a Depth of 2 Inches.		At a Depth of 8 Inches.	
Soot.	No Soot.	Soot.	No Soot.
62° F.	60°	60°	58°.5

The potatoes sprouted sooner beneath the soot, and the vines grew faster and more vigorously there; that is to say, the soot gave the plants a good start.

On the Rhine, it is said, grapes mature best where the soil has been covered with fragments of black slate; though it is not impossible, as some writers have urged, that a part of the useful effect may depend upon the fertilizing power of potash that is contained in the crumbly shale.

The geologist Bakewell, when travelling in Switzerland, in passing by a ravine near Tour, noticed a deep section made in a bed of very dark schist, that was covered on many parts of its surface with a saline efflorescence, which, as his guide informed him, was often licked off by chamois that descended for the purpose. "It is from this bed," he says, "that the inhabitants procure the black earth which they sprinkle over the snow to accelerate its solution in the spring. As the summers in this elevated situation are of short duration, it is of great importance to save time in getting their seed into the ground, and it was probably accident which first discovered to them a fact, now well known in natural philosophy, that dark surfaces are sooner heated by the sun's rays than white ones. It was proved by the experiments of Franklin, that black cloth laid upon snow caused it to melt faster than where it was uncovered, by absorbing the sun's rays, which are in a great measure reflected from the surface of the snow itself. The simple process of sprinkling the surface of their fields with this black earth makes the snow melt many days sooner than it would otherwise do; but our guide informed us, it was sometimes a tedious labor, for if any fresh snow should fall, or be drifted over the black earth, the operation must be repeated. We saw several heaps of this black earth collected near the cottages, to be ready for the following spring."

In a series of experiments upon potatoes, the French chemist Girardin found that the times at which the crop ripened varied from 8 to 14 days, according to the character of the soil. At a given date (the 25th of August) he found 26 varieties of his potatoes ripe in a very dark soil charged with much organic matter, while upon sandy soil there were but 20 varieties ripe; in clay 19 varieties, and on a white limestone soil only 16.

Oemler has tested a variety of air-dried soils of different colors, as to their power of absorbing heat when exposed to the sun's rays. His results are given in the following table:

	Average Absorption of Heat.	Percentage Absorption.
Moor earth	24.40	100.00
Fine dark brown humus	23.25	95.29
Sandy humus (50% humus)	22.75	93.24
Dark reddish brown sand	22.65	92.87
Loam rich in humus (20% humus)	22.10	90.57
Clay " " " "	21.40	87.70
Reddish yellow loam	21.00	86.07
Light gray clay	20.00	81.97
Fine sand, containing a little loam	20.75	85.04
Limestone colored with blue phosphate of iron	20.70	84.83
Coarse sand	20.50	84.02
Pure chalk	19.77	77.90

Schübler long ago examined a variety of soils as to the influence of color upon their temperature. A table of his results is given in "How Crops Feed," p. 196.

Wollny also found, from the results of numerous experiments, that a dry soil is generally warmer in proportion as the color of its surface is darker; and that, as a rule, for soils that are tolerably nearly alike as to their condition, color has no inconsiderable influence on the temperature of the soil, even at appreciable depths. This influence of color varies, of course, according to the time of year and the time of day, and as the sky is clear or cloudy. The greatest differences were found when the temperatures of the soils were highest. At times when the earth attains a daily maximum of temperature, in summer sunshine, a soil will be decidedly warmer in proportion as its color is darker. But during the colder seasons the differences in temperature between dark- and light-colored soils are less emphatic, and they are less noticeable below the surface. Both elevation and depression of temperature are more rapid in dark than in light soils, and dark-colored soils are consequently liable to wider daily variations of temperature than soils of lighter color. The dark soils cool off more rapidly by night than the light-colored soils, although the temperature falls no lower in one than in the other. By the time the temperature of the twenty-four hours has fallen to its lowest point, it appears that all differences between the temperatures of soils of different colors have disappeared.

For the experiments in question boxes were filled with dry white quartz sand, upon the surface of which was sifted a thin layer of the coloring matter, in the same way that Schübler had done previously.

For one set of experiments the coloring matter consisted of mixtures of lamp black and marble powder in the proportions of $\frac{3}{4}:\frac{1}{4}$, $\frac{1}{2}:\frac{1}{2}$, and $\frac{1}{4}:\frac{3}{4}$; while for another set of trials hydrated oxide of iron and marble powder were mixed in similar proportions. One box was strewn with pure lamp-black and one with the iron oxide. All of the boxes were shielded from rain, and two thermometers were sunk in the earth of each box. The bulb of one of the thermometers was placed four inches below the surface, while that of the other was just covered with earth. The thermometers were observed every two hours during the twenty-four, and the figures in the table represent the means of all the readings by day and by night. The lamp-black experiments are given in the first part of the following table, and those with iron oxide in the second. The figures denote degrees of the Centigrade thermometer.

	At Surface.				Four Inches deep.			
	Black.	Dark gray.	Med. gray.	Light gray.	Black.	Dark gray.	Med. gray.	Light gray.
28, 29 June, 1879,	32.82	32.39	31.98	30.94	28.33	28.46	27.83	27.20
Variations . .	34.55	32.90	32.45	30.10	15.20	14.25	12.50	11.85
	Dark brown.	Med. brown.	Light brown.	Faint brown.	Dark brown.	Med. brown.	Light brown.	Faint brown.
28, 29 June, 1879,	31.76	31.65	30.93	30.70	27.29	27.19	27.34	26.40
Variations . .	31.95	31.75	29.90	27.65	12.30	12.15	11.80	10.75

It is interesting to observe, in all such experiments, that a mere superficial layer of the coloring matter imparts its character to the soil beneath it; and that the whole of the soil behaves as if it were as capable as the matter which covers it of absorbing the sun's heat.

It should be borne in mind, that the question of the absorption and radiation of heat is usually complicated with that of reflection, and that in many instances the reflective power of a soil may be as important for the crop as its power of absorbing and radiating heat. Thus in some accounts of the Rhine vineyards it is reported that the vines are kept low and as near the soil as possible, in order that the heat of the sun may be reflected back upon them from the ground during the day, and that the process of ripening may go on through the night by virtue of the heat radiated from the earth. Here both reflection and radiation are sought for, and it might perhaps be possible to profit from both by strewing two kinds of stones, or say black coal and bright tin.

It is to be remembered that smoothly polished surfaces reflect heat more completely, while they absorb and radiate it less easily,

than substances which are rough, — all this quite independent of color. Sand, for example, reflects a large proportion of the sun's heat, vastly more than dry humus would; but what heat the sand does absorb it holds comparatively well. Substances differ widely withal in their capacities for absorbing heat of different degrees of intensity. Some things, like lamp-black, absorb and radiate all kinds of heat equally well; but there are other substances, such as white-lead and snow, which, while they can readily absorb heat of low intensity, such as is radiated from a can of hot water, or from earth or stones that have been heated, have comparatively little power to absorb intense heat, such as comes from a lamp, or fire, or from the sun.

Loose incoherent sands, especially if they are dark-colored, may become hotter in sunshine than other soils. Even in temperate climates, Arago found the temperature of sand on the surface to be 122° F.; and at the Cape of Good Hope, Herschel observed it to be as high as 159°.

Gravel retains Heat better than Sand.

As a rule, soils that become warm the quickest cool off most rapidly and are subject to the widest variations of temperature. The greater the weight of a given bulk of soil, — in other words, the larger and denser its particles, — so much the longer will it retain heat. Gravel cools much more slowly than sand. It remains warm much later in the night. Hence gravelly soils are esteemed to be "early" by market gardeners, and are known to be well suited for the ripening of grapes; not to say of potatoes, in cold, dank latitudes. It is precisely in the matter of spring vegetables and delicate fruits that considerations like the foregoing have their application; they are comparatively unimportant, however, with regard to many crops. Evidently they can have little bearing in the case of crops whose foliage covers the surface of the ground; their influence will then be limited to the time during which the soil remains bare after the seed is sown. Malaguti and Durocher have shown in fact that land covered with grass sod is cooler (in summer) than bare land. A thermometer bulb sunk four inches deep under greensward showed the same temperature as one sunk seven inches in the same soil when bare. In South America it has been observed that a bare granite rock marked 118° F., while an adjacent rock that was covered with grass marked 86°.

The warmth of gravel may be illustrated by that of rocks and

masses of masonry. The following paragraph is quoted from Dr. Hooker's "Himalayan Journals."

"We encountered a group of Tibetans encamped to leeward of an immense boulder of gneiss, against which they had raised a shelter with salt-bags. . . . They were crouched round a small fire of juniper wood. . . . A resting-house was in sight across the stream, — a loose stone hut, to which we repaired. I wondered why these Tibetans had not taken possession of the hut before we arrived, not being then aware of the value they attach to a rock, on account of the great warmth which it imbibes from the sun's rays during the day, and retains at night. This invaluable property of otherwise inhospitable granite I had afterwards many opportunities of proving."

The same thing is shown very emphatically in cities, where masses of brickwork cool off but slowly by night.

Oemler determined the time required by different soils to cool down to 59° F. after they had all been equally heated to 122° F. His results are given in the following table: —

	Minutes consumed in Cooling.	Comparative Power of retaining Heat, Coarse Sand being taken as 100.
Coarse sand	192	100.0
Fine sand	175	91.2
Loam	166	86.5
Pure clay	161	83.9
" chalk	158	82.3
Loamy humus	156	81.3
Clayey humus	152	79.2
Sandy humus	142	74.0
Fine humus	127	66.2
Moor earth	120	62.5

Moisture keeps Soils cool.

The influence of moisture in the soil upon its temperature will be treated of under Draining. It need only be said here, that the presence of varying quantities of moisture in the soil makes it difficult to experiment satisfactorily upon points like those of the absorption, radiation, and reflection of heat, to which reference has just been made. It is a very difficult matter in the field to eliminate this disturbing element of moisture, so that the amount of heat really due to absorption can be accurately measured, in any given case.

When speaking of making soils warm by means of dark-colored matters placed upon them, it is important to insist that neither swamp mud nor black loam is at all suitable for the purpose, be-

cause such muds and peats have an enormous capacity for holding water in their pores, and when the sun shines upon them this water absorbs the heat of the sun, and is thereby changed to vapor, which flies off and carries the heat with it, so that the effect of the peat may really be to make the land cool in spite of its black color. It is much as when a man sits in damp clothing in a breezy place. Lampadius's black coal-dust, and the black slate of the Swiss mountaineers, are true examples of the significance of dark-colored materials. Neither of these things would be likely to absorb enough moisture to interfere with their proper action as absorbers of heat. Dr. Hooker's rock also was a compact mass free from moisture.

One highly important fact in respect to the transmission of heat is, that, while the sun's rays can readily pass through the air, without sensibly heating it, to warm the earth by their impact, heat such as is radiated back from the earth to the air cannot so easily pass through it. Hence atmospheric air, and particularly the vapor of water in the air, acts as a cloak or screen to hinder the escape of heat which the earth has received from the sun.

"Turn of the Year."

One circumstance that needs to be kept in view when discussing the influence of light and heat upon the growth of crops is the time of year. Winter rye, for example, sown in the spring, will not grow as well as when sown in the autumn (or as spring rye sown in the spring), although to all appearance the conditions (warmth and light included) in the spring may be specially favorable for vegetable growth. Gardeners are familiar with the fact, that many kinds of plants grow better in greenhouses at some times and seasons than at others. In general it is thought to be well by greenhouse men to delay sowing many kinds of seeds until the "turn of the year." That is to say, they prefer to sow seeds in January rather than in December. Vilmorin, in calling attention to the dissimilarity of behavior of various plants in this respect, has stated that, while the term of growth of strawberries, melons, and grapes may be much shortened in a heated greenhouse, that of wheat, rye, oats, and turnips remains very much the same, as it is naturally out of doors. As he puts it, strawberries, melons, and grapes seem to be wellnigh indifferent to the season. They can readily be forced to grow fast at any time when constantly exposed to high temperatures.

CHAPTER III.

RELATIONS OF WATER TO THE SOIL.

The importance of water for the plant, and its uses also, in some part, will have appeared from what has already been set forth; but there is still much to be said concerning the water in the soil.

The most familiar source from which any soil derives water is rain, and it is certain that the agriculture of a country, and indeed the power of a country to support inhabitants, must depend upon the amount of rain that falls within or near its limits.

The first question to be considered is, What becomes of the rain-water that has fallen upon the earth and has soaked into it? And this question can perhaps best be answered by considering some special instances where the conditions are not complex.

Between the large islands Nantucket and Martha's Vineyard, off the southern coast of Massachusetts, there is a little sand island called Muskeget, which, like thousands of other similar islands, well illustrates the subject now under consideration. Muskeget is a mere sand-heap, a mile or so across, elevated a few feet above the surface of the ocean and kept from blowing away by a scanty growth of beach grass. But on digging down two or three feet anywhere into this sand, which was brought there by ocean currents, and is kept there by conflicting tides, a well of fresh water may be obtained. Whence comes this water? Manifestly from the rain that falls upon the island; for modern investigations have clearly shown that particles of mere silicious sand have no such power of removing saline matters from solutions as would serve to make sea-water fresh.

In the well-holes on the island now in question, the fresh water falls and rises slightly as the tide of the ocean ebbs and flows, and so it should, to accord with our theory. The water of the wells is nothing but rain-water which, falling upon the sand, has been absorbed by it, as by a sponge: and the supply of fresh water in the island is kept up by the rainfall.

No doubt the sea-water outside tends incessantly to diffuse into the fresh water, and to percolate through the sand towards the heart

of the island; but this process of diffusion takes time, and, as things now are, it can never be completed. No doubt thorough diffusion and penetration would ensue if there should happen to be at Muskeget a long series of years without rain. But as matters really stand, every new rainfall pushes outward the line of brackish water about the shore, and a state of equilibrium is maintained which enables the fishermen to get fresh water by digging only a few feet back from the sea-beach.

We have in the foregoing illustration an exceedingly simple instance of a state of things which exists everywhere, in all kinds of soils. Rain falling from the clouds soaks into the earth and remains there as "ground-water," at a height determined by the head of water around it. The surrounding water may be that of the sea immediately, as at Muskeget, or, as most commonly, it may be other ground-water in the soil of adjacent fields dependent finally for the most part upon the back action of brook- or river- or sea-water for the height at which it stands. An instance has been noticed where the back pressure of the river Rhine at high water affected the height of water in a well 1670 feet distant from the river's edge, and Chaumont has noticed also in Hampshire, England, that a well 83 feet deep and 140 feet above mean water level was affected by tides in the Hamble River, at a distance of 2240 feet.

In studying this subject, it will be instructive to reflect upon what must happen to the rain-water which falls upon a narrow, isolated ridge of gravel, and to consider how the draining away of water from the gravel, which is now rapidly accomplished, would be retarded if the ridge were to be sunk in the sea almost to the level of its summit; or if, instead of water, the ridge were to be completely surrounded with earth of one kind or another. Whenever water gets enclosed between impervious beds or layers of soil, a flowing spring may often be had by pricking the superimposed layer. From causes like this fresh water sometimes spouts up from beneath the sea. It did so formerly in Boston Harbor, at a point now covered by Long Wharf. Were there no sea around Muskeget, if that island could be left in the air high and dry as a hill of sand, most of the water would soon drain out of it, and holes might be dug in the sand in vain.

So too, if numerous powerful pumps were set in action to draw water from the wells in the sand, sea-water would eventually soak

into them. Roberts has described a condition of things at Liverpool which consists very nearly with the last-named supposition. He says that beneath the buildings and pavements of that city there are pebble beds, in the so-called Bunter sandstone, which are overlaid by a thick layer of impervious boulder clay. Every day several millions of gallons of water are pumped out from wells sunk in the pebble beds, though from the circumstances above stated it is impossible that much, if any, of this water can have percolated directly down from the surface into the sandstone. Manifestly this large supply of water must come from some distant source; and, from the observed fact that the water of the wells becomes more and more brackish with the course of years, it is evident that, ever since the wells have been established and drawn from, sea-water from the river Mersey has been continually percolating in towards the wells; that is to say, experience shows that the ground-water proper to the locality is not in sufficient quantity both to push back the sea-water, as of old, and to supply the new drain occasioned by the continual pumping from the wells.

As one example among several, Roberts gives analyses of water taken from a well situated 800 yards from the river Mersey and 500 yards from the nearest dock:—

Salts in Solution in the Well-water.	Grains per Gallon. In 1867.	In 1871.	In 1878.	In the River Mersey.
Chloride of Sodium	....	133.44	208.64	....
Chloride of Magnesium	....	49.01	63.49	....
Chloride of Calcium	....	51.45	69.26	....
Total chlorides	....	233.90	341.39	1334.9
Sulphate of Lime	....	26.55	37.38	....
Carbonate of Magnesia	....	2.22	1.16	....
Carbonate of Lime	....	8.68	6.58	....
Nitrate of Soda	....	....	2.15	....
Total solids	231.00	271.35	388.66	1505.0

Between the years 1867 and 1871 the salts increased 19.63%, and between 1871 and 1878 they further increased 40.64%. The rate of increase during the first period was almost 5% per annum, while during the second period it was nearly 6%. This difference consists with the fact that much more water was pumped from the well during the second period. Since 1871, 295,200 gallons daily have been taken from the well, or very nearly 90,000,000 gallons per annum. There are several such wells within a mile of the river,

yielding daily several million gallons of water. This yield has been continuous for many years, but the water has become more brackish each year, so that in some cases it is now half as salt as sea-water.

The Soil a Moistened Sponge.

The soil upon the earth's surface, with much of the rock also, may be regarded, at least in those parts of the world that are proper for agriculture, as if it were, like the cited sand island, a great sponge full of water up to a certain height. Near the surface, it usually happens that this sponge of earth is merely damp, and not actually wet. Here its pores are full of air, and only some comparatively speaking small quantities of moisture cling to the solid portions of the earth by force of capillary attraction. But at and below a certain small depth all the interstices of the sponge of earth are filled with water, so that there would be a continuous sheet of this liquid were it not for the fact that the fluid particles are separated from one another by the solid particles of soil. Out from the lower, i. e. the wet portion of the sponge of earth, there is everywhere a constant slow draining away of ground-water into and towards the sea; just as there is at Muskeget after a fall of rain has made the head of water within the island greater than the head of water in the sea outside. As was said, the water in the wells there sinks and rises accordingly as the fall or rise of the tide decreases or increases the external head.

This draining away of the ground-water is of course impeded here and there by the presence of impervious layers of soil or rock, such as were just now alluded to; but these hindrances are of exceptional character, and their existence does not in any way invalidate the general argument.

The growth of trees upon places like the Milldam in Boston, and the little oases of upland which occur frequently upon some of the salt marshes of the New England coast point out, as well as the sand island, the presence and the source of ground-water.

Movements of the Ground-water.

Yet another illustration may here be given, which is perhaps even more striking than either of the foregoing, inasmuch as some of the conditions of the experiment were artificial.

It is but a few years, comparatively speaking, since the large tract of land in Boston known as the Back Bay district was covered to no small depth with salt water. The Back Bay, which formerly lay behind the city, has been filled up, since 1858, with clean sandy

gravel, so that the surface of the soil, on which houses are now built, is elevated a considerable number of feet above the salt-water level. At the beginning of the operation of filling, a railway was run across the middle of the bay on piles, and the gravel was dumped into the water by car-loads in such manner that every load of the gravel was thoroughly soaked with salt water, excepting that very small proportion of the whole which went to form the uppermost layer or surface of the land.

In 1870, when the outer edge of a part of the filling was just beyond Dartmouth Street at the west, and at the line of the Providence Railroad at the south, as it had been then for five or six years, there was still — at the point where the Albany and Providence railways intersect — a little pool of water that was separated but a few feet from the salt water of the unfilled bay by a low, narrow strip of gravel. On noticing that frogs lived in this pool, I had some of the water from it analyzed, to see how much saltness the creatures could withstand. To my surprise, it appeared that the water was fresh water.

Following up the inquiry, analyses were made of ground-water taken from several different points upon the filled land, the samples having been collected at a comparatively dry time from holes that had been dug for the purpose of sawing off the heads of piles upon which buildings were to be erected. The results of the analyses[1] are given in the following table.

	grm.
1. One litre of water taken from frog puddle at the intersection of the railways contained of common salt	0.3699
2. One litre from a well-hole at corner of Berkeley and Boylston Streets (Hotel Berkeley)	0.3363
3. One litre from a well-hole, then not far from the unfilled bay, on Dartmouth Street, opposite the Museum of Fine Arts . . .	0.6604
4. One litre dipped from the still open bay, between the two railways	17.2196
5. One litre dipped from the open bay, half-way between Dartmouth and Parker Streets	18.1428
6. One litre dipped from the open bay at another point, nearer Charles River	20.1459

At the time these analyses were made there was a narrow line or ditch of fresh water on the south side of the Providence Railroad

[1] These analyses were made by my lamented friend, Wm. Ripley Nichols, subsequently widely known as an authority on the chemistry of waters, who was at that time my assistant in the laboratory of the Massachusetts Institute of Technology. — F. H. S.

filled with rushes and flags, and other fresh-water plants, although the land where the ditch then was had been filled in but a few years, and was separated from salt water by nothing but the low railroad bed. From all these facts it appears that, in the course of the few years which had elapsed since the land had been made, the ground-water of the soil had pushed out almost the whole of the salt water with which the gravel must have been saturated at the time of the filling in.

In so far as the water in it is concerned, the whole territory had in fact arrived at the condition proper to a normal soil. Fresh water could be had upon it anywhere, as it can now, by digging wells of very few feet in depth. It was noticeable, furthermore, in 1870, as it has been in more recent years, that in the spring-time the ground-water stands at a much higher level in the excavations that are made in this land for laying the foundations of houses than it does in midsummer or early autumn, after time has been afforded for the water derived from the rains of winter and spring to drain away into the sea. One conclusion to be drawn from this fact, which seems indeed to have been fully impressed upon the minds of builders, is that piles had better be driven in late summer or early autumn, so that their heads may be sawn off without any such expense for pumping out the foundation trenches as has to be incurred whenever the level of the ground-water has been brought somewhat nearer the surface by the rains of late autumn, winter, and spring.

The Water-Table.

It is this ground or bottom water, — subsoil water, or underground water, as it is often called — which supplies wells and springs, and for that matter brooks and rivers, at all times excepting those when rain- or snow-water is flowing off the surface of the ground. It is impossible to insist too strongly upon the enormous importance of it for the growth of crops.

Engineers call the upper surface of ground-water the "water-table," and they are familiar with the fact that it lies at very different depths in different soils and places, and at different seasons of the year. Sometimes the water-table is at the very surface of the ground, or at a depth of no more than a few inches or a few feet, while in other situations it may lie perhaps hundreds of feet below the surface of the land. Much depends on whether the soil is porous or compact, whether or not the upper soil is underlaid by

impermeable strata, and whether or not there is ready opportunity for the water to flow out sideways and so escape from the soil.

The position of the water-table, i. e. the height of the ground-water, is continually changing, and the rate of change naturally varies very much in different places. Generally speaking, the distance between the highest and lowest points reached by the water-table in the course of a year amounts to several feet at the least. At Munich, for example, this distance is estimated at 10 feet. But in some places the rise and fall of the ground-water may be no more than a few inches in the course of the year. At Saugor, in Central India, the water-table is but a few inches below the surface of the land in the rainy season, while it is 17 feet deep in May. At Jubbulpoor it is 2 feet from the surface in the wet season, and 12 or 15 feet in the dry season.

The rate at which the ground-water drains away may depend not only on the amount of the rainfall and of the back pressure from brooks and rivers or from the sea, but on the amount of water that flows in from behind, as it were. It has sometimes been noticed that rains occurring in distant places may cause the ground-water to rise, notably on plains which lie at the foot of hills. Occasionally in such situations the effect of rains may not be felt until several weeks, or even months, have elapsed since they fell.

Wells and Ponds.

An ordinary well is nothing but a hole sunk a little below the level at which ground-water habitually remains in the soil. It is a hole made large enough to contain an amount of water somewhat greater than is likely to be consumed at any one moment or hour. A pond is often nothing but a large well. An Artesian well is a boring that is, generally speaking, driven until it reaches ground-water that is supplied from some distant source. Sometimes the Artesian boring reaches water which is confined under pressure, and then a fountain or "flowing well" is obtained. Years ago, water was obtained for several manufacturing establishments on the Cambridge marshes by boring down through the peat into the water-bearing subsoil below the lowest depth of the salt water of the river. From these wells the fresh water had to be lifted, of course, with pumps.

There is a simple device for reaching the ground-water that finds much favor in this country, which consists simply in driving narrow iron tubes into the ground to a point below the level of the

water-table, and then pumping the water through the tubes. The first length of tube is closed at the very end, but has many small holes bored through its sides near the end. This first tube is driven into the soil with sledge-hammers; a second length of tube is then screwed to it, and driven down as before; then a third length is screwed on and driven; and the process is continued until the level of the water is reached.

On attaching a pump to the tube, and working it, quantities of sand and fine earth are brought up with the water at first, so that a sort of reservoir to collect and hold a supply of water is soon washed out around the bottom of the tube.

This method can hardly be applicable in stiff clays, or where there are rocks or boulders in the soil; but for many loamy, sandy, and gravelly regions it has great merit. It is readily applicable on low-lying, sandy plains, and has often been found invaluable by armies of invasion, as in the war of the rebellion, when it was invented, and more recently by the English armies in Abyssinia and Egypt.

Height of Ground-Water Variable.

As was just now said, the height of the ground-water, that is to say its distance from the surface of the earth, varies greatly at different times in any given soil according to the permeability of the soil, and to the time which has elapsed since heavy rains. More or less ground-water will naturally be present according as a season is wet or dry, and as less or more time has been allowed for it to drain away. Its movements are usually slow after the first flush of water caused by spring rains has subsided.

When people speak of wells and springs as being "full" or "low," their meaning is that the ground-water is up or down. So too, a "never-failing well" is one that has been sunk so deeply into the domain of the ground-water that the store of water in the soil is ample, even in late summer, for the demands that are made upon it. It happens constantly, of course, in many places, that before the supplies of such a well are wholly exhausted by the natural draining away of the ground-water and by pumping they are replenished more or less completely by new falls of rain.

Many interesting observations upon the flow, or rather the percolation of ground-water, have been made by engineers in various localities when studying the question of supplying potable water

to towns, — notably in connection with the water supply of Brooklyn, N. Y., as well as that of Munich and that of Berlin.[1]

Grading and Excavating may do Harm by changing the Position of Ground-water.

In the vicinity of a growing city the significance of the ground-water for the support of vegetation is constantly brought to notice by the sufferings of large trees near places where the land has been considerably disturbed, either by excavating or filling, as where banks of gravel are dug down, or roads and avenues are built. It will constantly be seen in such cases, even where no roots have been laid bare, that trees pine away or die simply because their relations with the ground-water have been disturbed. A tree may suffer from this cause either because the water can now drain away out of the land more quickly and completely than was possible before; or because, conversely, the building up of a new bank of earth has put a check upon the old system of drainage, and compelled the ground-water to remain so long upon the roots of the tree that they are smothered or "drowned out."

Even in cities, highly interesting effects are often produced by processes of grading or excavating. In Boston, for example, there is a district lying around Church Street which was originally low land that sloped gently down to the water's edge. This declivity was built upon many years ago, long before there was any thought that the Back Bay just now spoken of would ever be filled up. But as soon as the Back Bay had been filled with gravel to its present high level, the Church Street district, lying behind it, so to say, and at a lower level, became undrainable, and as good as uninhabitable, not only because the water proper to it could no longer find an outlet, but because ground-water from the comparatively high new land soaked out continually upon the lower tract which lay beside it. To obviate this trouble all the houses upon the older land had to be raised up by means of screws, and gravel was thrown in beneath them until the surface of the land was almost as high as that of the adjoining new tract. But one of the results of this operation was to make a new stretch of table land behind houses facing the Public Garden, and into the cellars of some of these houses ground-water immediately proceeded to flow, to the great annoyance of the occupants.

[1] Compare W. R. Nichols in his book on "Water Supply," New York, 1883, p. 105.

Several other similar instances that have occurred in Boston might be mentioned. One set of men will build houses just above the marsh level; but directly another set of men will fill in the land next adjoining to a proper height, and from this higher land the ground-water will inevitably flow towards the lower. Next the city authorities step in, and raise, at great expense, the houses on the low tract, and in so doing usually cause the difficulty to pass along to a new place. The houses upon the region about Dover Street in Boston, for example, have been lifted twice during the last forty or fifty years at the cost of the city, and gravel has been thrown in beneath them to raise the grade of the land.

Rate of Percolation of Ground-water.

An interesting example of the rate at which water percolates through soil is afforded by the Natron Ponds between Cairo and Alexandria in Egypt. These so-called ponds are a series of rock-walled basins about thirty-five miles west from the Rosetta branch of the Nile. They are fed by infiltration from the Nile, whose waters take three months or more to percolate through the interjacent desert of sand and rock. Thus, the annual rise of the Nile culminates in the third or fourth week of September, after which the water of the river begins to fall gradually; but the annual rise of the water in the Natron Ponds begins only about the end of December, and continues till the middle of March, when the fall commences.

The water that percolates through the desert dissolves out from it a quantity of carbonate of soda and common salt, and carries them into the ponds; and when the water evaporates during the summer, these saline matters crystallize out, and are collected and sold, as they have been time out of mind.

Best Height for Ground-water.

The height of the ground-water may be ascertained in any special case by noting that of the surface of a well, or any open ditch or hole in which water is standing. But it is to be observed that the water in such ditch or well is usually a little lower than that of the water in the soil.

It must be remembered also, that the foregoing statement would rarely be true for a stiff clay soil. In clay soils the wells are commonly "over-shot wells," as the term is; i. e. they are mere pits to receive and hold the surface water, which flows into them at the top.

The proper height at which ground-water should stand in order best to conduce to the prosperity of the growing plant is a question of no little complexity. There are numberless swamp plants which prefer to have their roots constantly immersed in ground-water. Rice also, and the cranberry, and ribbon-grass, and a few other useful grasses, flourish with their roots actually wet. But as a general rule the plants of cultivation cannot bear such an excess of this kind of moisture; it is with them much as it is with green-house plants, there must be a hole in the bottom of the pot or the plant will drown.

Many plants having powerful roots do indeed send some of them down to the bottom water. There are innumerable examples upon record, for that matter, of the choking of drains by the roots of various kinds of clover, and of turnips, grape-vines, and the like. As has been shown withal, under the head of Water Culture, it is possible to grow a great variety of plants in mere water. But in spite of all this, it is notorious that plants flourish best in soils where the ground-water is several feet distant from the surface of the soil. In the cultivation of moors and bogs in Europe, it is held as one essential condition of success that the ground-water must be kept at least three feet below the surface of the land in summer, and as much as two feet below the surface in winter.

The comparatively low temperature of ground-water is undoubtedly one reason why the too close proximity of such water is obnoxious to plants. A distinction must always be carefully made between running water like that of a brook, or of an open drain even, and the cold sluggish ground-water. A noteworthy example of the distinction to be made in this case is to be seen in the floating islands of the old Mexicans, as well as those still to be seen in China and in Cashmere. These islands were great flats of basket-work made strong enough to carry a layer of earth, which was of course kept continually moist by the water of the lake on which the island floated. But the ground-water in the earth of these islands was really the surface water of the lake, i. e. a warm, living water, in every way fit to be used for irrigation. The roots of the maize and of the various kinds of vegetables that were grown upon these floating islands must have been continually immersed in the ground-water; but, precisely as in the case of the experiments in water culture, the ground-water was of a kind that did the roots no harm.

For many crops — perhaps for most crops — it is held that where the soil, though light or gravelly, is in good heart, the ground-water should be from four to eight feet distant from the surface. The grasses, however, and some other plants, such as squashes and potatoes, succeed well in certain soils where the ground-water is very much higher than this.

Almost any one can recall from his own observation plots of grass-land where the ground-water is at just the right height for this kind of vegetation. At the banks of brooks it might perhaps be said that the influence of flowing water is felt, and that the observed luxuriance is due to irrigation from the brook rather than to the presence of ground-water. Usually, however, this conception would not be true; for in the generality of such cases it is ground-water percolating towards the brook that supplies moisture to the grass. Just so it is on the bottom lands of rivers (intervales), and in reclaimed bogs.

A low-lying slope, like the parade ground on Boston Common, is apt to have ground-water very nearly right for grass. This parade ground would be a fine mowing-field if soldiers could be excluded and boys decimated. Very much depends, of course, on the texture of the soil. Clayey soils retain their ground-water with great tenacity, and are often, on that account, unfit for general culture until drained by artificial means.

Some interesting examples, where the presence of ground-water at just the right height makes the cultivation of mere sands possible, are recorded by Boussingault. In a certain district in Spain there were a number of sand dunes composed of sand so loose and dry that it drifted hither and thither with the wind. But since the lower portions of these hills were kept continually moist by the infiltration of water from the Guadalquivir, it was only necessary to remove the loose sand from above the moistened layer, in places where no great amount of labor was required, in order to obtain some very fertile land; i. e. a soil which united in the highest degree two essential conditions of fertility, porosity and a constant supply of moisture. The climate, moreover, was specially well suited for land thus moistened, and it was found in fact that the levelled dunes yielded abundant crops, particularly when the sand was manured. This instance is closely related to the so-called method of sand culture, which has been successfully employed in many scientific experiments. One great merit of the method, as

has been urged by Hellriegel, depends on the remarkably complete manner in which the roots of plants develop in the incoherent sand. A perfectly developed system of roots occupying every part of the soil proper to it must manifestly be particularly well fitted for taking nourishment from that soil, and from the water that comes to it.

I have myself noticed an instance somewhat analogous to the foregoing, on the bank of the Merrimack River, on the line of the railway, not far from Concord, N. H., where mere sand lying upon high bluffs upon the river's bank yields crops in spite of the very unpromising appearance of the land. The explanation in this case appears to be that the sand is fine enough to be capillary, and that the ground-water is continually percolating through the bluff towards the river, at a depth from the surface not too great to put it out of reach of the crops. Indeed, the history of the improvement of sand dunes by plantations of trees is full of instances of the advantages to be derived from the ground-water when it is near enough to be accessible to the roots. The idea is simply, that, where there is ground-water within reach, trees can be started, and wherever this can be done the action of wind upon the loose sand in the vicinity can be checked, and the dunes thus be kept quiet enough to admit of grass, and finally trees, being grown upon them. In Holland, the best possible potatoes are grown on sand dunes, thanks to the presence of ground-water and the free use of manure.

In some localities, the presence of beds of clayey loam, at a depth of a few feet beneath the surface, permits profitable crops to be grown continually, although nothing but sand is to be seen where the plants are standing. It is manifest, in such cases, that the capacity of the subsoil to hold a store of moisture is the salvation of the farmer.

Upon the slopes of hills, there is generally a strong probability that somewhere, i. e. on some part of the slope, ground-water may be found at a good height. It is for this reason, doubtless, as much as on account of the soil which has been washed down from above, that so many of the hill farms of New England are situated near the bases of sloping hills. Indeed it might almost be urged as a general rule, that the positions of homesteads and of farms in Northern New England have been determined by the position and character of the ground-water as much or more than by the quality of the soil. The house was put where water could be got handily;

but where water can be got handily, crops will flourish. Of course, as the country has dried up through the destruction of woodland,—or rather of the mossy humus which the wood protected,—the relations of the ground-water to the surface soil have been greatly changed in many places. In the beginning, even the roads had to be carried along the high ridges in order that they should be moderately dry, during the rainy seasons, and that they should dry off after rain.

It is very noticeable that the most successful market gardeners in the vicinity of Boston keep near the ground-water. That is to say, they cultivate low-lying land for the most part,—often that which is very low. And it is true, in general, that the differences noticed in the fertility of fields or districts depends as often, or perhaps even more frequently, upon the presence in the soil of good supplies of moisture, as upon the stores of plant-food of other kinds than water.

In exceptionally dry seasons, indeed, access to the ground-water may become an absolute necessity for the success of crops, as may be seen from the following experiments by Wilhelm. It happened that an unusally small amount of rain fell in Germany during the autumn of 1865 and the following winter, while from March to July, 1866, the rainfall was very nearly equal to the average for that season. But, because of the previous lack of rain, all kinds of crops were seen to be suffering from drought during the spring of 1866 excepting those grown upon fields low enough to be within reach of the ground-water.

In order to determine how large the deficiency of water really was, samples of soil were collected at different depths in March and June, and examined as to how much moisture was contained in them.

I. *From low-lying fields, moistened by the ground-water.*

SAMPLES OF MARCH 2.

At Depth in Feet.	Kind of Soil.	Amount of Water in 100 Parts of the Fresh Earth.	Amount of Water for every 100 Parts of Dry Earth.
½	Loamy marl running to	16.92 — 18.84	20.37 — 23.22
1½	sandy marl and to sand,	18.01 — 20.81	21.96 — 26.28
2½	according to the depth,	21.61 — 24.26	27.57 — 32.03

SAMPLES OF JUNE 18.

½		18.86	23.25
1½	[As above.]	21.19	26.88
2½		21.56	27.44

II. *From upland fields, above the influence of the ground-water.*

SAMPLES OF MARCH 6.

At Depth in Feet.	Kind of Soil.	Amount of Water in 100 Parts of the Fresh Earth.	Amount of Water for every 100 Parts of Dry Earth.
½	Sandy marl	7.20 — 10.96	7.76 — 12.31
1½	Quicksand	2.32 — 5.09	2.38 — 5.37
2½	Sand and gravel	0.65 — 1.07	0.66 — 1.09
	SAMPLES OF JUNE 18.		
½		9.74	10.79
1½	[As above.]	4.92	5.17
2½		0.66	0.66

Soakage of Rain-water.

One point of primary importance which it would be well for every farmer to know about if he could is that classed by engineers under the head "percolation of rainfall"; for speaking in general terms it is true of most localities that, next to the amount of rain that actually falls, no one of the conditions which determine the success of crops is of more importance than the capacity of the soil to absorb and hold a good store of the water that falls upon it.

As is well known, the amount of rain which falls upon the land varies widely in different regions. Of some countries, such as Peru and a part of Egypt, as well as of the deserts of Africa and Central Asia, it may be said that no rain ever falls there. Upon the table-land of Mexico, and in many other localities, rains are very rare. Speaking in general terms, the most abundant rainfall is in regions near the equator, where there are usually regular wet and dry seasons; though in certain localities, as in some parts of Guiana, it rains wellnigh continually. Nevertheless, taking the year through, there are commonly fewer rainy days in the tropics than in the temperate zones. While as many as 95 inches of rain may fall at the equator in 80 days, there are some 170 rainy days at St. Petersburg, although no more than 17 inches of rain falls there in a year. In the northern portions of the United States there may be some 130-odd rainy days in the year against perhaps rather more than 100 in the Southern States. The average rainfall in the temperate zone is something like 35 inches, though there are wide variations in different countries. Some 25 inches of rain fall in a year at London, and nearly 280 inches at Vera Cruz.

It would be well for every farmer, doubtless, if he could but know about how much rain-water will soak into and pass out from

the soil of each of his fields in the course of a year, and how much at each season of the year. Many experiments have been made, indeed, in various localities, in order to ascertain what proportion of the rain-water that falls on a given field passes into or through the soil.

As Lawes and Gilbert have put it, the amount of percolation-water passing through any soil depends, first, on the amount of the rainfall; secondly, on the physical condition of the soil, i. e. its permeability and water-holding power; and, thirdly, on the amount of evaporation that is taking place. This evaporation, which depends largely on the temperature of the soil and of the air, and upon the capillary power of the soil, is often greatly increased when crops are growing upon the land, both because the foliage presents a large surface for the evaporation of rain-water which collects upon it and clings to it, as is seen very conspicuously in woodland, and because the crops pump up much water from the soil and transpire it as vapor from their leaves into the air.

Evaporation must often be very large, even where no crops are growing, as is shown conspicuously when rain falls upon hot sand. At the extremity of Cape Cod a brisk summer shower falling upon the shingled roof of a house will be seen to add several barrels of water to the contents of the cistern which supplies the needs of the family. But such a shower hardly leaves even a momentary impression of moistness upon the bare sand which surrounds the house.

As regards permeability, Hellriegel has shown that, while rain-water will soak into a soil so much the faster in proportion as the particles of the soil are coarser, it is still true that where there are layers of coarse and fine particles the latter will take up and hold the largest amount of water. The fine earth may even suck water out from the layer of coarser materials, and, in general, it will not give up water to the coarser layers until it has itself become surcharged.

Drain-Gauges.

The usual method of studying the question of the percolation of rain-water is to establish drain-gauges in the soil of the field which is to be examined. So long ago as 1796–98, the English chemist Dalton sunk a cylinder three feet deep and ten inches in diameter into the soil, filled it with earth, made it level with the surface of the land, and after the first year grew grass upon it. By collect-

ing the water at the bottom of this cylinder, he found that 25% of the yearly rainfall had percolated through the earth in it. The difference he attributed to evaporation.

Simultaneously with Dalton, Maurice at Geneva, using an iron cylinder filled with earth, found that the percolation was equal to 39% of a rainfall amounting to 26 inches per annum. Gasparin, in the South of France, in 1821–22, noted 20% of percolation from a rainfall of 28 inches. Dickinson, in England (in 1836–43), at a locality where the average rainfall was 26.6 inches, used a Dalton drain-gauge 3 feet deep and 12 inches wide, filled with gravelly loam and grass-grown at the surface. He found, as the average of eight years' observations, that 11.3 inches percolated in a year, or about 42.5% of the rainfall, while 57.5% either evaporated or remained in the soil. In round numbers $\frac{2}{5}$ of the rainfall in this case would pass out from the land through the drains, though very considerable variations were noticed, ranging from 33 to 57%, in the course of the experiments. Or, stated in other terms, while the annual rainfall ranged from 21 to 32 inches, and amounted to from 2.137 to 3.139 long tons to the acre, the annual evaporation was from 43 to 67% of the rainfall. The mean winter rain of the eight years, i. e. from October to March inclusive, was 13.95 inches, of which 10.39 inches percolated, or 74.5%; while the mean summer rain of the same years, viz. between April and September, was 12.67 inches, of which only 0.9 inch percolated, or 7.1% of the rainfall of these summer months. During the warmer months of the years 1840 and 1841 absolutely no water percolated through the drain-gauge.

Risler in Switzerland (1867–68), by gauging drains that had been laid 4 feet deep in a compact impervious soil, which bore crops at the time of the experiment, found that 30% of the average annual rainfall of 41 inches percolated, while 70% of it evaporated.

Pfaff in Erlangen, and Woldrich at Salzburg and at Vienna, found that only $\frac{1}{4}$ of the yearly rainfall percolated through two feet of bare soil when evaporation was greater than the rainfall; that almost $\frac{1}{3}$ percolated when evaporation was equal to the rainfall; and that rather more than $\frac{1}{2}$ percolated when evaporation was somewhat less than the rainfall. Woldrich found invariably that less water percolated 2 feet in soil upon which grass was growing than in a bare soil. Very light rains were wholly lost by evaporation from the grass, because the drops clung to the leaves until they

evaporated. During late autumn and winter the differences between the percolation in bare land and that which was grass-grown were less than they were from May to September. In January they were least, and it was noticed, when the ground was frozen and covered with snow, that the soil water in the bare land continued to sink to a greater depth than it did in the grass-covered earth. When the snow melted in spring, the water from it passed into the bare land much quicker and in larger quantity than it did into the soil that was grass-covered.

With the first awakening of vegetation in the spring, the differences between the bare and the grass land became more prominent, both because of evaporation of water that had clung to the blades of grass and because of the transpiration of water by the plants. The greatest differences were noticed in hot summer weather, viz. in June and July. In May not quite half as much water percolated through the grass land as through the bare earth; and during the last fortnight of June, at Salzburg, 23.16 lines of water passed through the bare soil against only 0.23 line that passed through the grass-covered earth. A similar contrast was observed in July also. The monthly differences between the bare and the grass-covered land were as follows: May, 25%; June, 53%; July, 23%; August, 29%; September, 12%. At Vienna in the winter 7½% less water percolated 2 feet in grass land than in land that was bare, while for the spring months the figures were 22¼%; or 15%, taking winter and spring together. At Salzburg 35¼% less water percolated through grass land in summer than passed through the bare land.

Some of the results of percolation experiments made in woodlands by Bavarian observers will be found on a subsequent page under the head of Mulching. In these Bavarian experiments it was found that in winter and spring rather more water dropped from drain-gauges that were 4 feet deep than from those 1 foot deep; i. e. within these limits of depth there was less water in the upper layers of the soil at that time of year than in the lower layers. In autumn and winter, on the contrary, the percolation water diminished as the depth of the gauges was greater. In summer, indeed, there was less than half as much water at a depth of 4 feet as at 1 foot. All of which illustrates the well-known importance of the store of water which accumulates in the land from the rains of late autumn, winter, and early spring.

From a rainfall of any given amount, more water will soak into the ground when it comes in the form of moderate persistent rain than when it falls in short heavy showers, and the fact is specially true, of course, as regards hillsides or any sloping land. But it has been found to be true, in Central Europe, that, excepting short sharp showers, more water will soak into level ground at a given time from a heavy rain than from two lighter rains yielding the same amount of water to a rain-gauge, manifestly because of the better chance for evaporation in the second case. In any event, the percolation of rain-water is greatly modified by evaporation; and since evaporation is much more rapid from the upper layers of the soil than from the lower layers, it sometimes happens that water may still be dropping from a drain-gauge even at a depth of one foot some considerable time after the last rain has fallen.

In Bavaria, much more of the water from a given amount of rainfall percolates in winter than in summer, because of the small amount of evaporation in winter; and for a similar reason much more of the rain that falls on a drain-gauge kept in the shade of a wood during the summer months will percolate, than can at that season pass through a drain-gauge kept in an open field.

In general, it appeared that, with the rapid increase of evaporation from May to the end of September the moisture in the soil diminished, while with the diminution of evaporation in October and the later months the moisture in the soil increased. So that, even if the amount of rainfall in late autumn and winter were to be considerably smaller than it is in summer, the amount of water in the soil would still be larger during the cold months than during those which are warm. In other words, the amount of water in the soil stands in no direct proportion to the rainfall of the several months.

In the same sense that tillage may promote percolation, by loosening and lightening the soil, so that water can freely enter it, so does a thick mat of vegetation hinder the admission of water. Any crop that stands thick, and fills the soil with roots that are entwined one with another, hinders the percolation of rain-water. Much less water will soak through grass sod than into bare earth, and European foresters have noticed a similar hindrance when the soil is covered with the matted roots of heath plants. On this account, it has been urged that, when young trees are to be planted, it will be best to remove heath, grass, or the like, and to cover the land with

a layer of loose litter, such as will permit water to pass through it. On the same account, it has been urged that large trees growing in a wood so situated that they get no other water than the rain which falls upon them may perhaps do better in case there is a growth of underbrush beneath them instead of a sod of grass; but in this case the water taken by the shrubs for their own support might perhaps more than counterbalance the increased soakage. The trouble with the grass sod, or similar mat, is not only that the plants use water and hold it upon their leaves to be evaporated, but that the felted roots offer a serious mechanical obstruction to the admission of water.

None of the water of light summer showers penetrates far into the soil in any event, because it evaporates from the upper layers of soil, and, from the causes just now enumerated, it may happen that such showers will be as good as lost on soils closely covered with vegetation. At some of the Bavarian stations, drain-gauges 2 and 4 feet deep, that were kept in open fields, gave out no drop of water during July, August, and September, and in two of the localities water ceased to drop from the one-foot gauge even in July.

As will be shown more in detail on a subsequent page, percolation may be greatly increased by hindering evaporation and facilitating the admission of water to the soil, as happens when leaf-covered drain-gauges are kept in the woods.

Wollny found that a calcareous loam which permitted 38% of the rainfall from April 14 to November 18 to soak through it, when it was bare of vegetation, percolated no more than 20% of the rainfall when grass or clover was growing upon it. In other trials, lasting from May to October inclusive, three different soils, viz. sand, peat, and clay, were compared side by side in three conditions; i. e. bare of vegetation; with grass growing upon them; and covered with a layer of horse manure $2\frac{1}{2}$ inches deep. The percolation was as follows, in per cent of the rainfall: sand, peat, and clay, when bare, 64, 44 and 32, respectively; when grassed, 14, 9, and 1; when mulched, 45, 39, and 49. The superiority of clay and peat as absorbents of water is manifest, as well as the pumping power of vigorous plants. The heavy mulch lessened the amount of percolation as regards sand and peat, i. e. as compared with the bare soils, but increased it in the case of clay. On repeating the mulching trials with a layer of horse manure only $\frac{4}{10}$ inch deep, the percolation was somewhat larger than through the bare soil, and evapora-

tion was less. A coating of gravel had the same effect as the thin layer of manure in lessening evaporation and increasing percolation.

No one has taken more trouble to study the subject of percolation than Lawes and Gilbert (1870–81), who built elaborate rectangular drain-gauges 6 feet by 7 feet 3 inches in area (= $\frac{1}{1000}$ of an acre). These gauges had depths respectively of 20, 40, and 60 inches. Care was taken to keep the soil in a perfectly natural condition of consolidation, so that it should neither be more porous nor more compact than ordinary field soil, and the surfaces of the gauges were kept bare of vegetation. The results of these trials have been tabulated for each of the several depths above mentioned, and for each month of each year during a period of ten years. The average rainfall of the locality and period being 31½ inches per annum, the mean yearly percolation through the drain-gauge that was 20 inches deep amounted to 14 inches; through the gauge that was 40 inches deep the percolation was 14.9 inches, and through the 60-inch gauge it was 13¼ inches.

As tabulated by Lawes and Gilbert, the percentages were as follows: —

During the	Mean Rainfall	Percent of Rainfall that went through the Gauge.		
	Inches.	20-inch.	40-inch.	60-inch.
4 years, 1871–74	27½	35.4	34.7	28.4
6 " 1875–80	34.2	49.6	54.2	49.4
10 " 1871–80	31.5	44.6	47.4	42.1

Naturally enough, some of these European experiences may not be directly applicable to a country the surface soil of which remains so long frozen as does that of the Northern United States, or to regions where the air is so dry as ours is, and which are subject to showers so violent as those we not infrequently experience. Moreover, rain falling upon our superheated soils in midsummer will be exposed to excessive loss through evaporation. Hence the special importance for us of American experiments. Dr. Sturtevant at South Framingham, Mass., found that of the annual rainfall of 47.15 inches, 8.7 inches, or 17.9%, percolated through the 25 inches of grass-covered sandy soil in his drain-gauge. Stockbridge at Amherst, observing during the seven growing months of the year, found that 5.14 inches of the 25.7 inches of rain that fell during these seven months percolated through 36 inches of a very leachy soil; that is to say, he noticed a summer percolation of 20%. During the same period, $27\frac{9}{10}$ inches of rain fell upon Dr. Sturtevant's drain-gauge, and $14\frac{7}{10}$% of the water percolated through it.

Professor Johnson calls attention to the fact, that, while the percentage of percolation is larger in England than in this country, the total amounts of water that penetrate the soil, as measured in inches, are not very different in the different countries. He cites the English results of Dickinson, Greaves, and Lawes, $11\frac{3}{10}$, $6\frac{9}{10}$, and 10 inches respectively, the Swiss results of Maurice and Risler, $10\frac{1}{2}$ and $12\frac{3}{10}$, the French of Gasparin, $5\frac{8}{10}$, and the American of Sturtevant ($5\frac{7}{10}$ in 1876 and $11\frac{4}{10}$ in 1877) and Stockbridge ($5\frac{14}{100}$ for seven months of 1877), in illustration of this view, and argues that the filtration of water through drain-gauges amounts to from 5 to 10 inches annually with a rainfall of 26 to 44 inches. Heavier rainfalls are evidently compensated by greater and more rapid evaporation; and evaporation and rainfall vary within much wider limits than percolation, which is relatively constant.

As a matter of course, water can percolate more rapidly through sand than through clay or humus; but it is nevertheless true, that soils and most rocks can retain some of the rain-water that falls upon them. The coarser the grain of the rock or of the sand, so much the more freely can water pass into and through it. As has been stated already, dry silicious sand can imbibe as much water as will amount to 20 or 25% of its weight. Engineers have noticed in the field that loose sands may hold two gallons of water to the cubic foot, and that ordinary sandstone may hold one gallon of water to the cubic foot. It is said that Liverpool sandstone, when saturated with water, can take up $\frac{1}{22}$ of its own weight of the liquid, and that $\frac{1}{10}$ will drain away by force of gravity, while $\frac{1}{12}$ remains fixed in the cavities of the stone by capillary attraction. According to Roberts, each cubic foot of this sandstone can store 0.733 gallon of water. Even the driest granites and marbles may contain from 0.4 to 4.0% of water, or perhaps as much as a pint in each cubic yard. Looking from the geological point of view, it has been argued in England, that, on an average, about 25% of the rainfall in that country penetrates into the chalk, and from 60 to 96% into the loose sands, while the remainder either runs off the surface of the land or evaporates.

CHAPTER IV.

MOVEMENTS OF WATER IN THE SOIL.

There are two kinds of movements of water in the soil. First the movement of percolation of the ground-water towards the sea, which is, on the whole, a downward movement; and, secondly, a movement by force of capillarity, which is, or may be, a movement in all directions in those parts of the soil which are above the ground-water proper.

The movement of percolation, caused by the ground-water seeking its level, is usually slow. It is retarded by a great variety of circumstances. Witness, for example, how much more slowly water drains away from a wooded country — covered with moss and leaves and vegetable mould — than it does from the same region when cleared. Even the roots of trees have been found to retard its movements.

Sometimes, as in a stiff, retentive clay, the movement seems to be as good as annihilated. Its sluggishness, in almost any soil, is made manifest when a deep well into which some impurity has fallen is left for a time to itself. It often happens in this event, that the water will long remain foul, so slow is the current that flows through or across the well. At Munich, Pettenkofer reckons the rate of the lateral flow of the ground-water at fifteen feet daily, while in the rather dense chalks of England engineers have supposed that the water moves three feet downward in the course of a year.

It is plain, on the face of the matter, that, in general, deep-lying ground-water can have comparatively little movement. Those portions of the ground-water, namely, which lie at a lower level than that of the brooks or ponds or wells into which the upper layers of the ground-water flow, cannot possibly find any easy outlet. To take again the example of the isolated gravel ridge with a brook flowing at its base, it is evident that the great mass of the ground-water that results from the rainfall will drain out from the ridge into the brook; but how is it with the water that lies deeper than the brook? Why, that will slowly drain away towards the sea, beneath the brook. It will drain away in the same general direction

as the brook flows, both beneath the line of the brook and beneath the plane of the brook. There is no longer any ready escape for it.

It follows, of course, that in a great number of instances deep ground-water must be more or less stagnant; and in fact it is found on boring or digging into such water, that it is apt to be either somewhat highly charged with saline matters which have been dissolved out from the rocks and gravel that are continually soaked by the water; or it is apt to be somewhat "sulphuretted," as the term is. That is to say, it tastes and smells feebly of sulphuretted hydrogen which has resulted from the decomposition of gypsum (or other sulphates) and organic matter, reacting one upon the other, in the stagnant water. Of the two most prominent artesian wells in Boston, one, at the gas-works, yields water which is decidedly saline; while the other, near the Providence Railway station, gives a somewhat sulphuretted water. But the soil of Boston rests in a great cup or depression, against one side of, or rather against the front, of which the deep sea presses, and so prevents the lower ground-water from draining out.

On examining the waters of several deep artesian wells in France, Gérardin found that they contained absolutely no oxygen gas in solution.

Professor Gregory of Edinburgh many years ago called attention to an interesting illustration of the movement of ground-water. He found that the carcass of a pig, buried on the slope of a hill which was moist and undrained, had in the course of 14 years shrunk into a flat cake, composed entirely of fatty acids, from the fat of the animal. Not only had the muscles and membranes, nerves and vessels, all putrefied and disappeared, but no trace of bone-earth was to be found. The whole of it had been dissolved — probably in much less time than the 14 years — by water percolating through the body of the animal. Gregory found that the water of the locality contained considerable carbonic acid, and it was evident that this carbonic acid had helped to dissolve the bone. But the fact that percolation must have occurred was manifest.

In general, it may be said that so long as springs and rivers flow there can be no doubt as to the movement of the upper layers of the ground-water.

Where to dig Wells.

The power possessed by some men of selecting places where wells may be dug with success depends upon a just appreciation of the

conditions which control the percolative movements of ground-water. There was a French Abbé years ago, named Paramelle, who became noted for his power of discovering subterranean water. Many powerful springs were opened by him, — ten thousand or more, of one kind or another, as the story goes. He was called to all parts of France to exercise his art, and, after practising it with great success, he published a book which describes his methods of procedure. The gist of his narration is simply that water tends to flow, i. e. it tends to percolate most freely beneath the lowest parts of valleys, ravines, furrows, gutters, slopes, and depressions of all kinds; that is to say, water stands or flows at precisely those places beneath the surface where it would stand or flow most readily on the surface if there were enough of it to reach the surface.

Causes of the Capillary Movement.

As to the causes of the movement of water by capillarity, it is to be noticed that the force of gravitation may at times exert some influence to accelerate the movement. Thus, when rain falls upon the earth, or when snow melts upon it, those portions of water which soak into the soil are speedily subjected to the influence of capillarity, and dragged downward. Even in the heaviest showers the rain does not penetrate as such to the depth of an inch. It is only when the capillary pores at the surface of the soil have become full that water passes downward into the pores which lie below the surface, and it is only when all the pores of the soil have become saturated by the capillary movement that percolation proper, due to hydrostatic pressure, can occur.

But at times when no water is coming to the land, either as rain or snow, the capillary movement is upward rather than downward, and it is occasioned, or rather kept up, by evaporation of moisture from the surface of the ground; and this evaporation may be due either to exhalation of moisture by plants, or to the direct action of sun and wind upon the land.

The actual movement of the water from below upwards is effected by the adhesion or surface attraction of the soil and the water, one for the other. The water tends to stick to the soil. A dry soil, like an empty sponge, drinks up, absorbs, and actually lifts the water; and beside all this there will be a movement of water through any soil that is moistened, even no more than very slightly, to make good whatever waste of water has occurred by way of evaporation from the contiguous parcels of soil.

There are two prominent facts to be held to: first, that the particles and pores of the soil absorb and hold rain-water that comes to them from above; and secondly, that the particles of soil and the pores of the soil above the ground-water proper suck up moisture from it precisely as a wick draws up oil in a lamp. Hence it happens, not only that moisture is left adhering to every soil to a considerable height above the ground-water after the draining away of the latter from any cause, and after every fall of rain, but that new portions of moisture taken from the ground-water are incessantly lifted through the soil, even to its surface, if not too distant, by force of capillarity, there to supply the place of the moisture which has been taken up by plants, or in any way evaporated from the surface.

This movement of water by capillarity is incessant, so long as there is any outgo of water from the upper layers of the soil, either from evaporation or from the exhalation by plants; and it is to be noted that the capillary movement is greatly favored by bringing the soil into a fine, porous, mellow condition by frequent tillage. As Professor Johnson has said, just as the strands of wicking in a lamp must neither fit too tightly nor too loosely in the socket in order to the best capillary action, so in the soil there is a certain degree of porosity which is best suited to the lifting of water.

Saline Incrustations upon Soils.

It is by this capillary movement of the soil water that saline matters are brought to the surface in many dry climates in such quantity as to incrust the surface of the ground throughout the summer season; and in this way, also, soluble matters necessary to the growth of the plant may be brought up out of the depths of the soil to the roots which feed upon them.

It is said that in some parts of Greece, after the rainy season has ended, and rapid evaporation of water from the soil has set in, saline matters rise to the surface in such abundance that the more tender herbage is gradually killed by them, and only very robust plants continue to grow. Even the growth of grass is prevented, although abundant wheat crops can be ripened every year, apparently because the more important part of the life of the wheat plant is finished before the land has become salter than the crop can bear.

Mr. Darwin has described in the following terms the incrustations of sulphate of soda admixed with common salt which he met

with frequently in Patagonia and other parts of South America. As long as the ground remains moist, he says, nothing is to be seen but an extensive plain composed of black muddy soil, supporting scattered tufts of succulent plants. On returning through one of these tracts, after a week of hot weather, one is surprised to see square miles of the plain white, as if from a slight fall of snow, here and there heaped up by the wind into little drifts. This latter appearance is chiefly caused by the salts being drawn up during the slow evaporation of the moisture round blades of dead grass, stumps of wood, and pieces of broken earth, instead of being crystallized at the bottoms of the puddles of water.

Illustrations of the Capillary Movement.

Experiments to illustrate the significance of the capillary movement of fertilizers have been made in ordinary earthen flower pots by cementing into the hole at the bottom of the pot a tube a foot or so in length, and filling both pot and tube with loam. The pot is then placed upon a rack in such manner that the lower end of the tube may dip into a fertilizing solution, such as barn-yard liquor, for example, or a solution of nitrate of potash. It is easy to see in this way that plants growing in pots whose tubes have access to plant-food grow much better than those so situated that the tubes dip into mere water. Moreover, by putting saline solutions at the bottoms of the tubes, and analyzing them occasionally, it will be seen how rapidly the saline matter is drawn up into the earth.

Nessler has illustrated the matter by experiments made to test the question whether moisture evaporates chiefly from the surface of the soil, or whether any considerable quantity of it can exhale directly into the air, as vapor which has formed in lower layers of the soil. He filled two cylinders with loam that contained 14% of moisture, and sunk them in the earth so that their tops were level with the surface of the ground. The loam in one of these cylinders was pretty firmly compressed, while that in the other was made to lie as loosely as possible in order that evaporation from its interior pores might be favored. Both of the cylinders were shielded from rain. In the course of six weeks 510 grm. of water evaporated per square foot of surface from the loosely packed loam, and 1680 grm. from the loam which had been compressed. Samples were collected for analysis, to the depth of about one line from the surface of the original soil, and of the loams in the two cylinders, and there was found in 1,000 parts of the

	Original Earth.	Loose Earth.	Compressed Earth.
Total soluble matters . . .	0.14	0.19	1.00
Organic " " . . .	0.06	0.08	0.32
Inorganic " " . . .	0.08	0.11	0.68
Potash	...	0.03	0.19

Whence it appeared that the evaporation of water was chiefly from the surface of the soil; that too much loosening of the earth diminished evaporation; and that substances such as potash, which tend to be fixed and held by the soil, as will be explained hereafter, do nevertheless move towards the surface in the current of the capillary water. But since, as a general rule, more water evaporates from soils during the summer months than comes to their surfaces as rain, more soluble substances will be brought to the surface in summer than will be carried down from the surface into or towards the subsoil.

In the field, when everything is favorable for the growth of plants, there is between the ground-water and the surface of the land a gradation of moisture ranging from the soil that is saturated or absolutely wet with moisture by mere force of capillarity to that which is nearly or quite "air-dried." It is capillary water which is seen when, on digging a few inches below the surface of the soil, even in midsummer, we find the earth to be, not dry and dusty but somewhat moist.

Frost in the Ground.

So too, when, as the saying is, the soil freezes in the winter, it is the capillary moisture in the soil that congeals to a greater or less depth accordingly as the soil is bare and exposed, or shielded from the cold as when covered with a mat of sod. Any covering of loose materials, as of snow, or straw, or leaves, or branches of evergreen trees, will greatly hinder the penetration of the frost, while in case the soil is firmly compacted, as on a well-worn or macadamized road, it may freeze to a great depth. A neat application of this knowledge is seen when excavations are made in cold autumn weather, and the workmen take care at nightfall to loosen a layer of the soil with their pickaxes, and to leave it lying until next morning as a mulch to hinder the soil beneath it from freezing.

In the spring, on the other hand, after extreme cold weather has ceased, and the frozen soil begins to melt, the moisture in the soil beneath the frozen layers often exerts a very marked influence to

accelerate the process of melting. That is to say, the comparatively warm ground-water and the capillary water that is lifted from it help to "draw the frost"; or, to state the matter in the language of the farm, when "frost is coming out of the ground," the moisture beneath the frost often assists very materially to hasten the process. Instances have fallen under my own observation in Boston where firmly frozen ground, that had been covered with a thick bed of gravel towards the end of winter, thawed out completely before the advent of spring. The land in question was coarse, loose gravel, and the original surface of it was no more than three feet or so above the ground-water.

As was said before, it is the almost invisible moisture held by capillary action in the soil, which in the main supplies both water and saline nourishment to the roots of cultivated plants. The little hairs with which the rootlets are covered (see "How Crops Grow," p. 245) cling tightly to the particles of soil, and extract therefrom the capillary water and whatever of plant-food this water holds in solution.

Capillary Power of Soils.

From the following table drawn up by Zenger, it appears that the capillary power of soils is greater in proportion as their pores are finer; but fineness of pores must not be confounded with fineness of particles. It is true enough that up to a certain point a soil will have more capillary power in proportion as its particles are more finely divided; but the moment this limit is passed, fineness is disadvantageous for capillarity, since the minute particles of earth are apt to cohere and cling together so closely that few if any open spaces are left between them for the admission of water.

The figures in Column I. of the table represent the percentage amounts of water that were imbibed by the soils which had been screened to a tolerably uniform state of moderate fineness, while in Column II. are given the percentage amounts of water imbibed by the same soils after they had been finely pulverized. It will be noticed that there is but little difference between the second column and the first in the case of soils which are naturally porous.

Other experiments have confirmed these results by Zenger. Thus, Wilhelm noticed, for example, that a garden loam that naturally imbibed 114% of water could absorb only 62% after it had been pulverized.

	I.	II.
Quartz sand	26	54
Marl	30	55
"Marl" from beneath a peat bed	39	49
Brick clay	66	58
Moor earth	105	101
Calcareous sinter	108	70
Soil from a moor meadow	178	103
Peat dust	377	269
Garden loam	123	...

The chemical character of a soil, though far less important than its porosity, may nevertheless have some influence upon the rapidity of the capillary movement, as may be seen on contrasting quartz and kaolin that have been reduced to powders of equal fineness. The quartz will absorb water considerably quicker than the kaolin.

The following table gives the water-holding power of a variety of soils as determined by different observers. The figures represent percentages of liquid water absorbed and held by the dry soils, as determined by soaking the weighed soils in water, allowing the excess of liquid to drain away, and again weighing the wet earth.

	Schübler.	Trommer.	Heiden.
Quartz sand with rounded edges	25	26	...
" " with flakes of mica	...	32	...
Limestone sand	29	29	...
Carbonate of lime in powder	85	80	...
" of magnesia	256	...	...
Gypsum (earthy)	27	...	...
Potter's clay	40	40	...
Loamy clay	50	50	...
Pure gray clay	70	70	...
White clay	...	74	...
Yellow clay	...	68	...
Elutriated feldspar	...	54	...
Silicic acid, as prepared from silicate of potash	...	241	...
Humic acids	181	...	1200 (from peat.)
Humus	...	180	...
Loam	52	...	40
Wheat soil	...	58	...
Fertile marly loam	...	59	...
Barley soil of second quality	...	47	...
Strong wheat land with 8 % carbonate of lime	...	61	...
Peat	...	...	201
Humus (not acid) prepared from peat	...	...	645

See also Meister's experiments in Hoffmann's Jahresbericht der Agrikulturchemie, II. 39.

Experiments have been made by Treutler to test the question whether or not the water-holding power of mixtures of different kinds of soils is equal to the sum of the water-holding powers of the substances when unmixed. It appears from his results, as given in the following table, that with few exceptions the power of mixtures to imbibe and hold water is less than that of their components taken separately. It is reasonable to suppose that, if the particles of each of the substances to be mixed were of equal size, the mixture would hold water as well as its components, as appears to be the case with some of the mixtures of fine earth and whiting or magnesia, in the table. But when the particles are of unlike sizes, the smaller ones fall into the spaces between the larger, and prevent water from occupying these spaces. Compare the mixtures of sand with whiting and magnesia.

In these experiments, 100 cc. of water and 50 grams of the substance to be tested were placed in a glass funnel, at the apex of which there was a small moistened filter which permitted the water that was not held by the earth to drain away. Each trial lasted 24 hours, excepting those with magnesia, which required 2 or 3 days, and those with bone meal, which required 10 days. In Column A of the table are given the number of cubic centimetres of water which were held by the earth, while Column B gives the sums of the absorptive powers of the components of the mixtures. Fifty grams of the substances named absorbed and held respectively the following quantities of water: —

Substances.	A. Found. cc.	B. Calculated. cc.	Difference. cc.
Fine earth	34.2	....	....
Quartz sand	14.0	....	....
Caustic lime	61.0	....	....
Whiting	25.0	....	....
Magnesia	230.0	....	....
Bone meal	46.0	....	....
40 grm. fine earth and 10 grm. lime	44.0	39.6	—4.4
30 " " " 20 " "	49.0	45.0	—4.0
25 " " " 25 " "	51.6	47.6	—4.0
40 " " " 10 " whiting	32.0	32.4	+0.4
30 " " " 20 " "	27.0	30.5	+3.5
25 " " " 25 " "	26.0	29.6	+3.6
40 " " " 10 " magnesia	73.5	73.4	—0.1
30 " " " 20 " "	112.0	112.5	+0.5
25 " " " 25 " "	133.5	132.1	—1.4

Substances.	A. Found. cc.	B. Calculated. cc.	Difference. cc.
40 grm. fine earth and 10 grm. bone meal	36.0	36.6	+0.6
30 " " " 20 " "	35.0	38.9	+3.9
25 " " " 25 " "	36.5	40.1	+3.6
40 " " " 10 " quartz sand	28.5	30.2	+1.7
30 " " " 20 " "	23.0	26.1	+3.1
40 " quartz sand " 10 " lime	19.0	23.4	+4.4
30 " " " 20 " "	29.0	32.8	+3.8
25 " " " 25 " "	34.5	37.5	+3.0
40 " " " 10 " whiting	12.0	16.2	+4.2
30 " " " 20 " "	12.0	18.4	+6.4
25 " " " 25 " "	14.0	19.5	+5.5
40 " " " 10 " magnesia	53.5	57.5	+4.0
30 " " " 20 " "	96.5	100.4	+3.9
25 " " " 25 " "	113.5	122.0	+8.5
40 " " " 10 " bone meal	16.5	20.4	+3.9
30 " " " 20 " "	9.0	26.8	+17.8
25 " " " 25 " "	8.0	30.0	+22.0
40 " " " 10 " fine earth	15.0	18.0	+3.0
30 " " " 20 " "	18.5	22.1	+3.6
25 " " " 25 " "	21.0	24.1	+3.1

The increased absorptive power exhibited by the mixtures of fine loam and caustic lime is probably due to granulation or "flocculation" of the earth by the lime, as will be stated more explicitly under the head of Tillage, though possibly it may depend on chemical combination, i. e. on the formation of a hydrated silicate of lime. The extremely large differences observed in the case of mixtures of bone meal and sand are admitted to be erroneous. The experiments with bone meal have little value, because it was a difficult matter to wet the meal in the first place, and because water dried off from it quickly. The greasy bone repelled water, and hindered it from flowing between the fine particles of the meal, and a part of the water that did adhere to the meal at first soon evaporated. Detmer also, experimenting with mixtures of sand and peat, found that by a mixture containing

Per Cent of Sand.	Per Cent of Peat.	There were absorbed Grams of Water.	If Sand = 1, the observed Absorptive Power =
100	...	12.2	1
80	20	24.0	2
60	40	42.0	3½
40	60	71.7	6
20	80	99.1	8
...	100	114.4	9½

The Capillary Force hinders Evaporation.

Naturally enough, the power of a soil to hold water tends to retard evaporation from the soil. The figures of the following table are Schübler's determinations of the amounts of water that evaporated from various wet soils (the same as those examined by him as stated in a previous table) in the stated times when these soils were spread out upon a given surface.

From the Wet	Of each 100 Parts of the Water in the wet Soil there evaporated at 60° F. in the Course of 4 Hours.	90 Parts in Hours.	Minutes.
Quartz sand	88 parts.	4	4
Limestone	76 "	4	44
Gypsum (earthy)	72 "	5	1
Potter's clay	52 "	6	55
Loamy clay	46 "	7	52
Pure gray clay	32 "	11	17
Fine carbonate of lime	28 "	12	51
Carbonate of magnesia	11 "	33	20
Humic acids	21 "	17	33
Loam	32 "	11	15

See also Meister's results in Hoffmann's Jahresbericht, II. 41.

It will be noticed that, in proportion as a soil absorbs more water by imbibition, so much the less water does it give off through evaporation. The powerfully absorptive soils not only lose comparatively little water through evaporation in a given time, but, from having a larger store of moisture, they can continue to meet the demands of evaporation through a much longer period than the soils which are comparatively speaking non-absorptive.

From some experiments of Sachs, it appears that plants cannot exhaust the retentive soils so completely of their water as they can the soils which are non-retentive. Thus, in a loam capable of holding 52% of capillary water, a tobacco plant wilted at night, when the soil contained 8% of moisture. In a mixture of humus and sand competent to absorb 46% of moisture, another tobacco plant wilted when the moisture had been reduced to 12%; and in coarse sand which could hold 21% of moisture, a third plant wilted when the proportion had fallen to 1½%. Here the plant was able to pump the soil almost absolutely dry. In these experiments 44%, 34%, and 19% of water, respectively, were more or less available for the plant.

Different kinds of plants appear to resemble one another more closely than would have been expected in respect to this power of

exhausting soils of their moisture, and the experiments of Hellriegel have shown that any soil can supply plants with all the water they need, and as fast as they need it, so long as the moisture within the soil is not reduced below one third of the whole amount that it can hold.

Influence of Humus and Clay on Capillarity.

From the tables above given it appears, as would be anticipated, that the best soils possess a medium absorptive power. The lack of this power in coarse sandy soils is doubtless one prominent cause of their sterility. On the other hand, the value of humus and of clay in a soil depends in great measure, no doubt, upon the facility with which these substances imbibe and retain moisture.

In general it may be said, that the larger the proportion of clay or humus in a soil, so much the more power will that soil have of holding water; while the water-holding power will be so much the smaller in proportion as sand is more abundant in the soil. While coarse gravel can be seen to suck up the ground-water to no greater height than an inch or two, good capillary loam may visibly lift it to a height of six feet. On the other hand, a small amount of rain-water falling upon the land may moisten a large volume of coarse sand, perhaps as much as twenty times its own bulk, while the same amount of rain-water might not moisten more than three times its bulk of cohesive clay. Numerous experiments by Meister upon the power of air-dried soils to suck up water from moist earth are recorded in Hoffmann's Jahresbericht, II. 42.

One merit of the ploughing in of green crops upon sandy soils is that humus is thus supplied to increase the capillary and the retentive power of the soil. In case this had been done with the third soil of Sachs, for example, it might perhaps have been made equal to the first soil.

It has been noticed, however, of soils too highly charged with some kinds of organic matter,—such as some reclaimed peat bogs,—that, though capable of holding much water when wet, they have only a comparatively feeble power of absorbing water when once thoroughly dried. Such soils, though wet and cold in the spring, may become so dry in summer as wellnigh to lose all power of absorbing moisture. Rain-water may even stand upon the surface of such soil for a considerable time without being absorbed to any appreciable degree. In some cases this behavior may depend on alterations in the actual physical texture of the peat induced by

drying; but it is probable that in other instances the peculiar repellent action of such peats may be due to the presence in them of waxy, resinous, and fatty matters, which coat the surfaces of the particles of peat and make them greasy enough to hinder water from adhering to them. It has been noticed by Hayes and others, that appreciable quantities of matters soluble in ether and in alcohol can be detected in most soils that are rich in organic matter, and there is no improbability in the idea that some soils may contain such things in considerable quantity. Fatty matters may be produced in the soil by the action of microscopic organisms, such as the butyric ferment; wax may come from the chlorophyl of decayed plants, and resinous matters from pine needles or the like.

Best Amount of Capillary Water.

As regards clay and humus, it should be said that it is bad to have too large a proportion of either of them in a soil because of their liability to make the soil too wet. Wet land is always cold land. It cannot be warmed rapidly by the sun, because water needs to absorb a peculiarly large amount of heat in order that its temperature may be increased, and because water carries away much heat when it evaporates. Many wet soils cannot be ploughed or tilled early in the spring, for reasons that will be set forth under Tillage, nor can air gain access to them when their pores are full of water.

It is a fact of observation, that plants are liable to sicken and die on soils that are too wet, the more readily, no doubt, in case the water becomes stagnant, and so occasions reducing chemical action such as gives rise to the formation of ferrous and sulphuretted compounds that are poisonous to most agricultural plants. Hellriegel finds that as much water as may amount to 80% (or more) of what the soil can hold is hurtful to ordinary agricultural plants, and that a soil charged with water to the extent of 50 or 60% of its capacity offers the best possible conditions for the growth of crops, when other circumstances are favorable.

Plants need so much water, and it is in general so important that the capillary and water-holding power of a soil shall be large, that it might be thought at first sight that the best soils would be those which can offer the largest amounts of water to crops. But, as has just been indicated, this conclusion can only be true for cases where the stores of moisture are not excessive. The living water of the Spanish sand dunes, before mentioned, and that of the floating

gardens, is a very different thing from cold or stagnant water, such as might clog or poison soils that are too rich in humus or clay. Examples of good capillary soils may be seen in many of the mixtures of peat, sand, leaf-mould, rotted sod, etc., which greenhouse gardeners prepare for the growth of ferns and certain other plants.

Ameliorants, so called.

The results recorded in the table above given explain at once the good effects which are often seen to arise from the application of various other substances besides humus, which alter the texture of a soil. It is a practical maxim, however, that while a small proportion of clay will greatly improve a light sand, a large quantity of sand is needed to correct the tenacity of a stiff clay. Other examples of the "amelioration" of soils are seen in the application of lime to clay, and in the burning of clay. The particles of burnt clay are no longer plastic and sticky, like those of the crude earth. In this sense, coal ashes are often valuable as an application to stiff clays.

A just conception of the mode of action of the capillary force may be got by considering a process of butter-making that was patented at Washington some years since. It is perhaps the more instructive because of its economic absurdity. It has long been believed by many agricultural populations, that cream wrapped in close cloths and buried in the earth over night may be changed to solid butter by morning. All the watery portions of the cream, with whatever the water may have held in solution, will be absorbed by the earth by virtue of capillary attraction, which drags the buttermilk first into the porous napkins and then into the soil. Acting on this idea the patentee buries his bag of sweet cream in a vessel filled with slightly moistened bran or with meal, and leaves it there for twenty-four hours. He then finds butter inside the bag, while outside the bag he has meal charged with butter-milk which he proposes to feed to hogs, or to other animals, as a most nourishing and fattening food.

Capillarity as modified by Hygroscopicity.

The main facts as to capillarity are evident enough, but some of the details[1] are sufficiently complex, as may be seen, for example,

[1] The agricultural student will do well to study the experiments of Johnson and Armsby in the Reports of the Connecticut Agricultural Experiment Station for 1877 and 1878; and those of Nessler in Hoffmann's Jahresbericht der Agrikulturchemie, 1873–74, I. 49.

on seeking to explain the manner in which moisture rises through the soil to or towards the surface of a high gravelly ridge. Here processes of evaporation and condensation within the soil come in to help the capillary movement, i. e. vapor exhales from that part of the soil which is moistened by simple capillarity, and this vapor is absorbed by the overlying soil. But when once the soil has become damp in this way, it is better able than it was before to lift water from the adjacent layers of soil, and the scope of the capillary movement is thereby extended.

Experimenters operating upon tubes standing in water, and filled with dry earth so arranged that samples of it could be taken out at different heights for examination, have found that the proportion of moisture in the columns of soil diminishes so gradually from below upward that it is wellnigh impossible to distinguish between simple capillary and hygroscopic movements, or to detect any limit of height at which water ceases to be absorbed. As evidence of the constancy with which the hygroscopic dampening precedes the capillary lifting, Wollny reports a trial where four tubes full of earth were made to stand up in a dish of water and were subsequently examined as to the amount of water that had disseminated itself in the earth. One of the tubes was examined at the end of an hour and a half, another after it had stood for a day, the third at the end of a week, and the fourth after five weeks. It appeared that the soil gradually took up more and more water, and continually lifted it to higher elevations, in such manner that it was evident that at any given height the soil must have passed through various stages or degrees of moistness before it finally acquired the full amount of water that it was capable of holding under the conditions of the experiments.

Speaking generally, it is plain enough that up to a certain height above the actual ground-water the pores of the soil will be completely filled with liquid, just as the pores of a lamp-wick are filled with oil, by force of capillary adhesion. But above this real or conceivable limit of absolute saturation there must be in multitudes of cases layers of soil that are only partially saturated by the capillary movement, and, above these, there will be other layers still less completely saturated; and so we may readily conceive of passing to heights quite beyond the scope of capillarity, in so far as it relates immediately to the ground-water, and come to layers of soil so elevated that, if no rains were to fall, the soil might soon become

nearly or quite air-dried between the uppermost limit of capillary action and the surface of the land. In the case here supposed, slow evaporation would naturally occur at the top of the uppermost layer of moistened earth, even when, as was just suggested, it is situated at some distance beneath the surface, and the vapor thus generated would slowly escape into and towards the air.

Practically, however, that is to say usually, in soils devoted to agriculture the earth is moistened by rain-water from above, as well as by water lifted from the permanent store below; and whenever liquid water sinks downward through the soil, very considerable quantities of it will be retained by the soil, no matter at how great a distance above the ground-water the surface soil may be situated. That is to say, much water will be retained both by soaking into the actual particles of the soil, and by clinging to the surfaces of the particles, especially at the points where the particles touch or nearly touch one another. The finer the soil, up to a certain point, so much the larger will be its power of thus retaining water, because of the great extent of surface presented by its particles; and a similar remark will apply to the condition of looseness, or rather compactness, in which a soil happens to be. In order to the best results, the soil must neither be too hard and compact, nor yet too loose.

It appears from all this, that it would be a matter of merely secondary interest in actual practice to know how rapidly water could rise in a dry soil of given character, or how high a level it could reach in such soil, since in nature the problem is seldom or never presented in that form. As Johnson and Armsby have urged, the tendency in the field is simply to preserve the original distribution of the water by a motion through the already filled or partly filled interstices of the soil toward the point from which water is being abstracted, — generally the surface.

Practically, water rises wellnigh continually from below to supply that wasted at the surface, and, excepting times of actual rain, this movement is doubtless very extended, since it is naturally transmitted from one particle to another even to considerable depths. A soil that will thus permit capillary water to move freely and rapidly within it, to supply a deficiency at any point, is said to be in good mechanical condition.

For soils that lie high above the ground-water, it is important that their texture and the crops may be such that the amount of

water evaporated into the air shall not be too largely in excess of the amount that can rise through the soil by virtue of the capillary movement. For success with timothy, squashes, and some other thirsty crops, it is wellnigh essential that the amount of water sent out into the air from the land shall be no greater than what can rise daily through the soil. It is noteworthy withal, that even coarse soils may often serve perfectly well for transmitting water upward, to supply that wasted by evaporation, in cases where the ground-water is high, i. e. near the surface of the soil. Here, mere permeability is all important.

Hygroscopic Moisture.

In connection with the retention of liquid water may be mentioned the power of the soil to draw in and hold small portions of the invisible aqueous vapor, which, as is well known, forms a constituent part of the atmosphere. That moisture can really be absorbed and held in this way is proved by the fact that a soil to all appearance dry, as it lies in contact with the air, will still lose weight when heated to 212°, the point at which water boils. It is found in practice that ordinary air-dried soils heated in this way during several hours invariably suffer an appreciable loss of weight which may range from less than 1% to 10% or more. Even the driest dust of the highway is by no means wholly free from moisture. When once within the soil, the hygroscopic water that has been absorbed from the air is not to be distinguished from the capillary water with which it may be said to mix.

According to Hilgard, the amount of hygroscopic moisture that can be held by cultivable soils when they are exposed at a temperature of 59° F. to air saturated with moisture varies from 1.5 to 23%. He finds that pure clay rarely holds more than 12% under these conditions, though ferruginous clays and some calcareous clays may hold from 15 to 21%. Peaty soils may hold 23%, or even more.

The power of the soil to absorb atmospheric moisture is of course nothing more than a particular instance of a very general law. There are hosts of things far more hygroscopic than any soil; wool and hair, for example, of which hygrometers are sometimes made. In selling silk in France, it is customary to make an allowance for the hygroscopic moisture. At the same time that a lot of silk is weighed for sale, a small sample is weighed out by itself, and the proportion of moisture contained in it is determined by drying.

The amount of water thus found is then subtracted from the weight of the undried portion of the silk.

Even dried plants or plant-roots will absorb more moisture from the air than most soils can absorb. Hay, straw, corn-stalks, and most other air-dried vegetable matters — even grain — usually contain some 10 or 12% of hygroscopic moisture, and when exposed to damp air they contain much more than these amounts. Trommer found that the following number of pounds of water were absorbed from moist air by

	In 12 hours.	In 24 hours.	In 48 hours.	In 72 hours.
100 lb. of fine-cut barley straw .	15	24	34	45
" rye straw	12	20	27	29
" white unsized paper .	8	12	17	19

Perhaps the most familiar instance of all is charcoal, which freely absorbs aqueous vapor from the air, as well as many other gases, to the extent sometimes of a quarter of its own weight. Charcoal that has been recently burned, or heated to expel the absorbed vapor, kindles very easily; whereas, in case it has been kept for some time in a damp place, it kindles with difficulty and snaps and smokes while burning. After having had occasion to use a charcoal fire, chemists sometimes throw any live coals that are left into an iron pot, which they cover tightly, in order to have a store of perfectly dry coal wherewith to kindle the next fire. After having long been stored in a damp cellar, charcoal and even fire-wood do not kindle readily.

Numerous estimations of the amount of hygroscopic moisture that can be absorbed by different soils have been made by different observers, notably by Knop and by Meister. The significance which such moisture may sometimes have for plants when all the conditions are favorable is well illustrated by the closed glass cases of Mr. Ward. In this apparatus, as was explained before, the soil is left to itself, after having once been watered, so that vegetation is subsequently supported by the water which the soil drinks in continually, as vapor, out of the air, as well as by condensed water, which in temperate climates trickles down from the roof and sides of the case. But at sea within the tropics where the temperature of air and water, and of things upon the water, is continually the same (almost 85° F.), there can be comparatively little condensation of vapor in a Ward's case. Here at least the atmosphere of the case is kept charged with vapor by the natural exhalation from the

plants, and the soil must drink in much of the vapor, as such. Once in the soil, the roots of the plants will again pump it up, to be again exhaled.

So too in the field cultivation of broad-leaved plants, — such as the whole tribe of turnips and cabbages, clover, Indian corn, squashes, and the like, — the ground doubtless reabsorbs a part of the aqueous vapor which is exhaled by the leaves, though this illustration is of course much less emphatic than the previous one. It is complicated, moreover, to a slight extent, by the consideration that the plants in question shade the ground, and so hinder somewhat the evaporation from the surface which would naturally be due to the action of sun and wind upon the soil; and by the fact that much dew condenses upon the great leaves by night, so that liquid water dribbles from them into the ground. In the tropics, in particular, where the nocturnal radiation of heat occasions very considerable differences of temperature between night and day, so much dew is deposited that in some localities it goes far to supply plants with all the moisture they need. It is said that in tropical forests so much dew condenses by night, that it may often be heard dripping from the leaves of the trees even at daybreak.

The absorption of moisture by the soil from the air naturally tends to increase by night and to diminish by day. Doubtless at some seasons of the year dry soils may gather in this way appreciable quantities of moisture, even when no dew is deposited.

Surface Soil often very Hot.

But it must be remembered that in droughty summer weather the surface of a dry soil may become very hot. Herschel observed at the Cape of Good Hope that the soil attained a temperature of 150° F., when the air was 120°; and Humboldt says that in the tropics the temperature of the soil often rises to from 124° to 136°. But a soil once thoroughly heated, even in temperate climates, will often remain so warm throughout the night that it cannot be in a condition to absorb much hygroscopic water. On the contrary, soils thus heated must often give off by night vapor that may perhaps have come from considerable depths, where supplies of moisture are held in store.

Nessler has observed in late summer, when the days are hot and the nights cool, that on placing an inverted glass funnel on the ground by night, much water will be deposited upon the inside of the glass; thus showing that a part of the moisture which, on such

nights, condenses as dew upon plants or other matters at the surface of the ground, has come, not out of the air, but out of the soil. Indeed, the moisture that in times of drought evaporates within the soil from those layers which are still moist, and passes up as vapor into the dry surface soil, is presumably much more important for vegetation than any vapor that is absorbed by the soil from the air. This subterranean evaporation must be strongest at times when the soil is most thoroughly heated in dry weather, and much of the vapor must condense near the surface whenever, as of an autumn night, this part of the soil becomes cooler than the layers of earth immediately below it. It is true, in general, that the air contained in the pores of the soil is decidedly damp, even if it is not actually saturated with aqueous vapor at no great distance below the surface, so that whenever the soil is cooled some of the vapor in it condenses and is deposited as liquid water upon the particles of earth.

It has sometimes been argued that the utility of the time-honored practice of frequently stirring the surface-soil in the dry season, by means of hoes or the cultivator, in order that the crop may not suffer from drought, is to be attributed to the increased power of the loosened soil to absorb the vapor of water from the air; but this explanation can no longer be accepted as a true one, since it has been shown that the amount of moisture thus absorbed from the air is wholly inadequate for the support of crops. The subject of summer tillage will be discussed in another connection.

Estimations of Amount of Hygroscopic Moisture.

Many estimations have been made of the amount of aqueous vapor absorbed by soils. Thus Davy found that, while 100 parts by weight of sands absorbed 0.3, 0.8, and 1.1 parts of moisture in an hour, loams absorbed 1.3, 1.6, and 1.8 parts. In these experiments the soils were dried at 212°, and then exposed to air saturated with moisture at 62°.

Schübler found that at temperatures of from 60° to 65° F., and in the times stated, 100 lb. of the substances enumerated in the following list absorbed from air that was saturated with vapor the number of pounds and tenths of pounds of water that are given in the tables.

	In 12 hours.	In 24 hours.	In 48 hours.	In 72 hours.
Quartz sand	0.0	0.0	0.0	0.0
Lime-stone sand	0.3	0.3	0.3	0.3
Lean clay	2.1	2.6	2.8	2.8
Fat clay	2.5	3.0	3.4	3.5
Clay soil	3.0	3.6	4.0	4.1
Pure clay	3.7	4.1	4.8	4.9
Humus	8.0	9.5	11.0	12.0
Garden loam	3.5	4.5	5.0	5.2
Loam from Hoffwyl	1.6	2.3	2.3	2.3
Loam from the Jura	1.4	1.9	2.0	2.0

Trommer also, operating on soils that had been dried at 212° F. and then exposed to air saturated with vapor, obtained the following results:—

	In 12 hours.	In 24 hours.	In 48 hours.	In 72 hours.
Stiff clay soil (wheat land)	3.5	4.0	4.4	5.5
Another wheat soil	3.0	4.1	4.8	5.0
Humic acids	7.5	9.0	10.8	12.8
White clay	4.0	4.6	5.0	5.5

Knop, who made many experiments upon this subject, was inclined to believe that the amount of vapor absorbed by a given kind of soil depends upon the temperature of the soil and not upon the amount of vapor in the air; but Hilgard insists that this statement is too strong. He finds that in some soils the amount of vapor absorbed from saturated air varies but little between 45° and 77° F., but always tends to increase with the temperature, while in other soils the increase of moisture absorbed is considerable, and may amount to nearly 0.1% for each degree Centigrade between 14° and 35°. From half-saturated air, on the contrary, absorption increases as the temperature falls, but to an extent varying with the degree of saturation, so that practically the general fact of absorption is in accord with Knop's view. Absorption will naturally be more rapid from moist air than from that which is dry.

An exaggerated view of the influence of temperature may be had by considering what happens during frosty nights, i. e. when the temperature of the soil is decidedly below the dew-point of the air, for then actual liquid water will condense in and upon the soil, and soak into it or freeze upon it. A small thermometer laid upon grass land by night, when all the conditions are favorable for radiation, may mark from 14° to 16° below the temperature of the surrounding air. Jourdanet has stated that certain marshes in Mexico cool so decidedly at night that they cease to be malarious for the time being, i. e. they are not dangerous by night. He reports that

a thermometer there indicated 32° F. at the surface of the ground, and 50° when hung 16 feet above the ground.

Professor Hilgard, who has devoted much attention in California to the absorption of aqueous vapor by soils, is convinced that the agricultural value of a soil depends in some part upon its power of absorbing vapor of water from the air, i. e. either from atmospheric air, or from ground air which has been charged with moisture as it lay in contact with lower layers of the soil.

All soils, he says, which can absorb no more than 2% of moisture at 59° F. when placed under the most favorable conditions are in practice droughty soils. Ordinary upland soils not easily damaged by drought can absorb at the best from 4 to 8%. Soils more hygroscopic than this are mostly heavy clays, whose resistance to drought is great when they are well tilled. He argues furthermore, that the evaporation of the hygroscopic water from a soil in times of extreme heat may act as a safeguard to keep the soil cool; i. e. it may hinder the soil from becoming so hot that the surface roots of crops would be destroyed. These considerations must be specially important in countries where rain falls only in winter, to be succeeded by long-continued dry weather, and where the success of crops is dependent upon the power of the soil to husband the supply of water within it until such time as the crop has completed its term of growth.

The importance of Hilgard's observations is the more conspicuous, inasmuch as they indicate the limitations of other experiments which have been made in mere pots of earth; i. e. under conditions where there can be no damp air continually rising from the subsoil to supplement and protect the capillary water, and to eke out the supply available for the crops. For example, Heinrich and A. Mayer have found that most plants wilt when the soil in which they are growing still contains considerably more moisture than it has the power to absorb when dry from moist air. Thus Heinrich, experimenting with oats and maize, found that the plants

Wilted when 100 Parts of the dry Earth contained Parts of Moisture	But 100 Parts of the dry Soil could absorb from moist Air no more Moisture than Parts	Kind of Soil.
1.5	1.15	Coarse sandy soil.
4.6	3.00	Sandy garden loam.
6.2	3.98	Fine sandy humus.
7.8	5.74	Sandy loam.
9.8	5.20	Calcareous soil.
49.7	42.30	Peaty soil.

Numerous other experiments with grasses and leguminous plants showed that in a calcareous soil capable of holding 5.2% of hygroscopic moisture the minimum of moisture for grasses was 9.85%, and for legumes 10.95. In a peaty soil competent to hold 42.3 of hygroscopic moisture, the figures were 50.79 and 52.87 respectively.

A. Mayer's experiments with peas showed that the plants

Wilted when Hyg. Moisture was	The dry Soil could absorb % of Moisture	Kind of Soil.
1.3	0.8	Sand.
33.3	16.3	Sawdust.
4.7	1.9	Marl.

Liebenberg, also, who experimented with beans, gives the following table.

Percent by Volume of Moisture in Soil when the Plants wilted.	Percent by Volume of Hyg. Water absorbable at 59° F.	Kind of Soil.
6.91	3.40	Marl.
10.02	7.46	Loam.
10.32	3.43	Granitic soil.
12.49	6.18	Sandy moor earth.
9.15	5.89	Calcareous soil.
1.20	0.46	Coarse sand.
0.51	0.19	Moderately fine sand.

Experiments recently published by Hellriegel seemed to enforce the conclusion that the amount of aqueous vapor ordinarily absorbed by soils from the air cannot be of much practical importance for the growth of crops. For in his trials the water thus absorbed by garden loam amounted to less than 2% of the weight of the dry earth, and to no more than 3 or 4% of the water that the soil was capable of holding, while plants could not grow at all in such soil unless it contained more water than amounted to 5% of its water-holding power, and even 10% was inadequate for the support of crops.

Fertility dependent on Moisture.

From all that has been said hitherto, it is evident that the fertility of any soil must depend in no small measure upon the behavior of the soil towards water, and upon its position or situation with regard to the ground-water.

If the earth be of such quality that it can imbibe moisture freely, and retain it tolerably forcibly, without impeding that capillary movement which is essential to the proper transfer and circulation of the water in the soil, and if at the same time the ground-water be at such a height that it favors the capillary movement, there

will be little risk that tillage and manure will fail of producing good effects. With an open sand or a close clay it is often difficult to fulfil these conditions. Through sand, rain-water runs away quickly, carrying with it mechanically some of the fertilizers which may have been applied, while into clay the rain-water can hardly penetrate at all. Unless it be improved by green manuring, or by the application of peat or clay, sand has comparatively little power to lift water by capillary action, or to hold it against evaporation. And, on the other hand, clays are apt to be so dense that they materially hinder the capillary movement.

The Rain that falls on a Field is insufficient for Large Crops.

The importance of the ground-water for agricultural crops, and the futility of trying to carry on productive agriculture without it, i. e. in places where the ground-water lies at so great a distance beneath the surface soil that it has practically very little influence on the growth of crops, may be shown very emphatically by carefully considering the question, Is the rain-water that falls upon a crop during the period of its growth sufficient for the support of that crop? Many European investigators have studied this question, and they have almost invariably found that it must be answered in the negative.

For most temperate regions it may be laid down as a rule that there is not enough rain-water for the support of really good crops. In many places there is not nearly enough rain-water. If any different conclusion from this could be reached it would follow that a much larger proportion of the earth's surface could be profitably cultivated than is now found to be possible.

Heiden illustrates the matter as follows. From Schübler's observations it appears that from a Morgen (= 0.631 acre) of land covered with short Poa grass, 6 millions of pounds of water will evaporate from the plants during the six summer months, and from a hop-field of similar area 4¼ millions of pounds. From Lawes's observations, moreover, it appears that a Morgen of wheat would send off 9 millions of pounds of water in the same space of time. Even if it were assumed that no more than twenty-five wheat plants grew upon each square foot of the land, that crop would require 2¼ millions of pounds (= 36,000 C. F.) of water. But it has been found at Königsberg that no more than 2½ millions of pounds of water fall during the entire year, the rainfall being about twenty-five inches; and it is to be remarked that out of

thirteen different German stations for rain-gauges only one shows a larger rainfall than Königsberg.

In the vicinity of Boston much more rain comes to the land than in North Germany, for the annual rainfall amounts to more than forty inches. But our storms and showers are so very unevenly distributed that even here the water supply cannot be regarded as particularly favorable for vegetation.

The contrast between the amount of water needed by crops, and that supplied directly to a field by rain, is all the more striking when we reflect how small a proportion of the yearly rain falls during the growing season, how much of it runs off the land anyway, or soaks away from the crop into the depths of the earth, and how much of it evaporates directly without passing through the crop. It has been thought in Germany that hardly one half of all the rain-water that falls in a year upon an acre of land can possibly be of any direct use to the crop that is standing upon the land.

Nevertheless, very much depends upon the time of year when the rain falls. Thus, in California, in the valleys of the Sacramento and San Joaquin, where the annual rainfall rarely exceeds twenty inches, and is often very much less than this, abundant crops of grain are obtained provided as much as twelve or fifteen inches of rain fall in late winter and early spring, for much of the water is absorbed by the soil, and held in store during the spring months; i. e. long enough to nourish the crops, and to enable them to ripen off before the dry season.

Evaporation versus Rainfall.

Extremely interesting tables, showing the differences that have been observed at various localities between the rainfall and the amounts of water that evaporate from open reservoirs, are given in the books that relate to hydraulic engineering; for example, in Beardmore's Manual of Hydrology, London, 1862, p. 296 *a, et seq.*

At London it is admitted that evaporation from the surface of water in an open reservoir is nearly equal in a year to the rainfall which occurs there. Howard at Plaistow found, as the average of three years, that 21 inches of water evaporated from the surface of a vessel in a year, while 23 inches were caught in an adjacent rain-gauge. Dividing the year into terms of four months, he found on the average,

	Rainfall.	Evaporation.
For the winter period	7.28	3.66
" spring "	7.79	10.41
" summer "	8.08	7.06

Vallé at Dijon, as the mean of seven years, found that 26 inches of water evaporated from a reservoir per annum, while the rainfall was 27 inches.

Hoffmann at Giessen observed that from May to September 457 tenths of cubic inches of rain fell, while 559 tenths of cubic inches evaporated from an open vessel that was charged daily with water. This evaporating-dish was placed in a garden six feet from the ground; it was somewhat shielded from wind, but not from rain or from the sun.

Golding at Copenhagen, as the mean of twelve years' observations, noted that the rainfall was 22 inches, and that the evaporation from a dish of water was 28 inches. He found also that 44 inches of water were exhaled in a year from long grass grown in soil kept saturated with water in a vessel that had no outlet, and that 30 inches were exhaled from a second plot similarly moistened where the grass was kept short.

Meister in Bavaria, and Grouven in North Germany, observed in the year 1863 that the amount of evaporation from the surface of water kept in the shade was larger than all the water that fell as rain, snow, dew, etc., during the year. Grouven found even that there were but two months in the year (March and November) when the rainfall of the month was larger than the evaporation from the surface of a dish of water.

Schübler claimed in his day that the average evaporation of water per diem during the growing season, from one square foot of surface, was, from water, 1 line; from sod, 2–3 lines; from bare soil, 0.6 line; and from woodland, 0.25 line.

Evaporation from the Soil.

The foregoing experiments, it will be noticed, refer merely to the evaporation of water from vessels artificially charged therewith. It was observed furthermore by Saint-Martin, long ago, and by F. Schulze, Wilhelm, Nessler, Ebermayer, and Masure, that more water may evaporate from a soil that is very wet than from mere water. This fact may be due in part to asperities of the soil which increase the evaporative surface, and in part perhaps to the color of the soil. It consists at all events with Wollny's observation that the heat absorbed by dark-colored wet soils accelerates the evaporation of water from them. Wilhelm urges that the evaporation from wet earth is more rapid in proportion as the surface is more uneven. When he separated the coarse from the fine portions of a soil and

moistened both, he found that the former lost water by evaporation much faster than the latter, because they exposed a much larger surface to the air. He suggests that in dry regions it is well, in order to retain in the soil the water that has been brought to it by the winter's rains, not to plough the land in the spring, or, at the least, not to leave it lying in rough furrows for any length of time at that season.

Schulze found at Rostock on the Baltic, during the six months May to October, 1859, that 596,000 grm. of water, or, in other words, a layer of water nearly 21½ inches thick, evaporated from an open vessel one square metre in area that was daily filled with this liquid. The vessel was kept on a stand three feet from the ground, in the middle of a garden that was somewhat sheltered from north winds, but was uncovered, and not shielded in any way from sun or air.

In contrast with the evaporation from mere water, a variety of experiments were made, in similar vessels, upon soils both in their natural state and when kept more or less saturated with water. In the cases where the earths were kept wet, the bottoms of the vessels were perforated, so that rain-water might flow through into a trap below. One set of vessels were charged with so-called dry earths as follows: white sea-sand, with a water-holding power of 26%, that contained 19% of water; garden loam, with a capacity to hold 94% of water, that contained 11%; and moor earth, the capacity of which for water was 170%, and which contained 49%. The mean daily evaporation of water from these dry earths, during the months stated, is given in the following table, together with the rainfall, comparative force of the wind, etc. The area of surface in each case was one square metre.

	Loam. grm.	Sand. grm.	Moor Earth. grm.	Water. grm.	Rain. grm.	Moisture of Air, %	Temp. °C.	Wind.
May,	630	965	751	4760	8864	67.5	13.7	20
June,	1041	1082	1160	4543	25927	76.6	16.9	14
July,	864	915	859	3563	32526	77.6	19.0	5
August,	1076	1093	1136	3245	69138	77.2	19.5	4

The rains of July were at the end of the month, and show their influence upon the increased evaporation of August.

Other experiments were made with loam that was kept half wet, i. e. half as much water was added to it as it could hold; and in other experiments both the loam and the moor earth were kept saturated to ⅔ their capacity. Finally, experiments were made

with fully saturated earths. From the fully saturated loam and moor earth the mean daily evaporation from a square metre of surface for the several months was as follows, rainy days being excluded from the account.

	Saturated Loam.	Saturated Moor Earth.
	grm.	grm.
June 25–30	7600	7783
July	4680	4935
August	4433	4600
September	2640	2713
October	972	1076

Whence it appears that the wet moor earth gave off water rather more freely than the wet loam.

The behavior of the partially saturated loam will appear from the following table, which gives the average daily evaporation, as before.

	½ wet Loam.	⅔ wet Loam.	Saturated Loam.	Water.
	grm.	grm.	grm.	grm.
June 25–30 . . .	6248	. . . .	7600	5587
July	4116	. . . .	4856	3847
August	3137	. . . .	4405	3448
September	2722	2965	3025	2659
October	1113	1181	1026	907

In the Bavarian experiments reported by Ebermayer, it was found, in general, that during the summer months rather more water evaporates from a layer of earth half a foot deep that is kept saturated with moisture, than will evaporate from an equally large surface of water, though occasionally the reverse of this is true, since much depends upon the amount of wind that blows. In woodland, where the movements of air are comparatively feeble, evaporation of water from the saturated earth is almost always larger than that from mere water similarly sheltered from wind.

Naturally enough the evaporation of water from saturated woodland soil, even that which is bare of leaves, is less than from saturated soil in the open. It was in fact from 61 to 63% less. From saturated woodland soil covered with leaves the evaporation was still less (22% less); i. e. both trees and leaves upon the ground beneath trees work to hinder the evaporation of water from the surface of the ground. In general, the evaporation of water from soil covered with litter and kept in woodland was 6½ times smaller than the evaporation from bare saturated soil in open fields.

At most of the Bavarian stations the yearly rainfall was larger than the amount of evaporation from the surface of water that was

shaded from the sun's rays and shielded from rain, but kept in open fields; while in the close forests the evaporation from dishes of water was so small as to be very much less than the rain and snow that came to the ground in such situations in the course of the year. During the summer months more water was almost always lost by evaporation from the dishes kept in fields than fell as rain, as had been noticed before by Hoffmann, Dufour, and others, while in the woods the rainfall exceeded the evaporation even in summer. In winter, when evaporation was small anyway, there was a great excess of rainfall both in the woods and in the open.

In the course of the year, 36 cubic inches of water evaporated on the average from dishes kept in the woods for every 100 c. in. that evaporated from dishes in the fields; i. e. evaporation from a sheet of water in the woods was 2.8, or 64%, less than in the fields. In summer, evaporation from dishes of water was four times more rapid than in winter, and it was nearly three times less rapid in the woods than in the fields. 429 c. in. evaporated in the woods in summer, and 111 c. in. in winter, while in the fields the quantities were 1223 c. in. in summer, and 314 c. in. in winter. It was noticed that by night evaporation was ½ to ⅓ less than by day.

Wollny found that water evaporated most rapidly from sand that was saturated with water, and least rapidly from peat thus saturated; while Haberlandt found that both sand and loam, even when they are not completely saturated with moisture, lose more water by evaporation than is lost from an actual sheet of water. So too Masure found that from a soil which is tolerably, but not excessively wet, water may evaporate just about as rapidly as from mere water; but from drier soils evaporation is not so rapid as from water by itself. He urges that the evaporation is less rapid in proportion as the soil is drier.

It is plain from all this, that the yearly evaporation from an actual field bare of vegetation must generally be less than the rainfall. In actual farm practice there must be wide variations in this regard, according to the character of the soil, the contour of the district, and the kind of vegetation, as well as the amount and the distribution of the rainfall. On a light soil bare of vegetation and fully exposed to sun and wind, evaporation will often be rapid immediately after rain; but when once the surface soil has become dry, the rate of evaporation may be greatly diminished. On the other hand, where crops are growing, the evaporation will be more con-

stant on the whole, though sometimes less conspicuous immediately after rain. From woodland in particular, there is always continuous and rapid exhalation of water from the foliage during the spring and summer months, although the surface of the ground is shielded so that comparatively little evaporation can occur there. Light showers, even though frequent, may be of little use to crops because of the rapid evaporation of the water which they have brought.

It appears that even frozen water, or rather melting ice, may serve as a useful store of moisture, at least in certain situations and for some crops. Mr. Barneby reports of Assinobia, on the line of the Canada Pacific Railroad, that even in late July some of the soil still holds the winter's frost at a depth of several feet below the surface. He says: "This underground layer of frozen earth is believed to explain the wonderful fertility of the soil; as the frost, in gradually coming to the surface during the summer months, creates a moisture which, meeting the warmth from above, forms a kind of natural hot-bed. This moisture counteracts the scarcity of rain during the spring and summer, and accounts for the grain being forced with such amazing rapidity after the late sowing; for in point of fact grain crops are not usually sown until early in May, and yet they are harvested at the end of August."

Modes of controlling the Ground-water.

It will be instructive to consider briefly what steps have been taken by farmers, at one time and another, to put the soils of their fields into proper relations with water.

The open ditch seen so often in bog-holes is one simple example. Instances are abundant where the level of the ground-water has been reduced by means of such ditches to a point which permits the cultivation of English grasses, potatoes, squashes, or the like; particularly when the excessively high capillary power of the bog earth is mitigated by a dressing of sand or gravel.

The method employed on the sunken polders of Holland is not dissimilar, though, in the lack of any natural outfall there, the ditches have to be pumped out continually in order that the ground-water may drain into them. In case a drought occurs, the pumps are stopped, and the ground-water is left in the land to support the crops.

Trees as Pumping Engines.

The planting of willows and poplars, that is to say, of trees that love water, is another device for drying over-wet meadows so that sweet grasses may work in. If, as has been shown, the exhalation

of moisture from mere grass sod can bedew and obscure glass in the twinkling of an eye, it is manifest that the great mass of foliage which is concentrated into the space occupied by a single tree must be an engine of no small power. In point of fact, trees do pump off and evaporate enormous quantities of water, and they thus hinder the stagnation of it beneath the soil.

Some idea of the efficacy of this method may be got by considering the amount of leaf surface which is presented by a good-sized tree. Professor Asa Gray computed, some years ago, that the Washington Elm at Cambridge, which, though a fine tree when in its prime, was never extraordinarily large, must produce every year some seven millions of leaves, equal to 200,000 square feet of surface, or about five acres. But since the crown of this tree is no more than about seventy feet in diameter it cannot cover as much as one tenth of an acre of land.

It is to the enormous extent of leaf surface thus presented to the air that the drying effect of trees must be attributed, for it is known that less water can evaporate from any limited area of leaf surface than evaporates from a similar surface of water. Unger found that, in general, about three times as much water evaporates from a measured surface of water as from a similar surface of leaves, and this conclusion has been corroborated by the experiments of Sachs. Occasionally, indeed, Unger found that the evaporation from water was five or six times larger than from leaves.

But it is none the less true, that, when vigorous plants are grown upon a given surface of soil, they will evaporate much more water than would evaporate either from the soil or from a water surface of similar area, because the evaporation from the leaf surface is added to that from the soil surface. Thus, in the experiments of Schulze, at Rostock, barley was sown in June upon garden earth contained in a vessel one square metre in area, and duckweed was floated on a square metre of water. Grass sod also, and other plants, were set out in garden earth contained in similar vessels, and all were copiously watered, and kept in a garden. Though some of the plants suffered from exposure to rain, and perhaps from improper transplanting also, they gave off very large quantities of water, as will appear from the following table, which gives the mean daily evaporation in lines from water in a dish, and from the several kinds of plants, as well as the rainfall, the humidity of the air, the temperature, and the force of the wind.

	Water. Lines.	Nightshade (Solanum nigrum).	Grass (Poa annua).	Barley.	Houseleek (Sempervivum tectorum).
June	2.05	3.13	2.92	2.08	. . .
July	1.60	3.27	2.74	2.58	. . .
Aug.	1.41	2.50	1.95	1.70	0.63
Sept.	0.81	. . .	1.44	. . .	0.35
Oct.	0.36	. . .	0.60	. . .	0.39

	Duckweed (Lemna minor).	Rainfall.	Moisture of Air, per Cent.	Temp. °C.	Force of Wind.
June	. . .	11.6	76.6	16.9	14
July	. . .	14.5	77.6	19.0	5
Aug.	1.54	7.2	77.2	19.5	4
Sept.	0.60	31.2	85.1	14.1	7
Oct.	0.30	6.4	92.9	9.5	5

On comparing the evaporative power of the plant Xeranthemum bracteatum with the evaporation from an exposed surface of water, Masure found that three times as much water was transpired by the plant as evaporated from the water surface. This consideration explains the detestation in which certain trees, such as elms and poplars, are held by most farmers and gardeners. Both these trees are thought to be specially prone to suck the land dry.

Pfaff, at Erlangen, in Germany, studied in detail the power of an oak tree to transpire water. He found that his tree had 700,000 and more leaves, which between the 18th of May and the 24th of October, that is to say, from the time the leaves appeared until they fell, transpired 264,000 lb. of water into the air during the daytime. But this amount of water was 8⅓ times more than fell as rain upon an area equal in circumference to the tree top. In addition to this, it is known that about one quarter of the summer rainfall may cling to the leaves of trees and evaporate therefrom.

In a similar way, Vaillant observed that an oak tree, 69 feet high and 8⅔ feet in circumference at 3¼ feet from the ground, transpired of a fine summer's day 4,400 lb. of water.

European foresters have often noticed that clay lands are apt to become wet, and gradually to get into a springy or swampy condition, after trees have been cut off from them; and that, conversely, such lands dry out when new trees have been planted upon them, and have attained to some size.

In studying this subject, Risler dug up samples of earth from contiguous fields, on which different kinds of plants had been grown, or were growing, and determined how much water was contained in the earth in each instance. The soil of the locality was a stiff clay,

and the conditions to which the several fields were exposed were similar, excepting the differences due to unlike crops. The pieces of woodland were some 25 or 30 acres in extent.

Date.	The Samples of Earth were taken from	Per Cent of Water in the Soil, at a Depth of 6 to 8 in.	16 to 18 in.	Mean.
Aug. 25.	An unplanted part of a garden not far from fruit trees	15.00	17.00	16.0
" 26.	A field that had borne winter vetches, and had been ploughed after the harvest in July	11.00	18.20	14.6
" 26.	A stubble field, not touched since the oats were harvested	7.57	17.38	12.5
" 26.	Woodland, oaks 9 years old	10.57	13.95	12.3
" 26.	Woodland, oaks 35 to 40 years old . .	9.53	7.54	8.5
" 26.	Woodland, spruces 20 years old . . .	12.85	4.46	8.6
" 24.	Vineyard	9.25	10.41	9.8

Not only did it appear that towards the end of August the woodland soils had become drier than those of the garden and fields, but it was noticed that in the subsequent months the forest soils became drier still, for the rains of early autumn happened to be light, and a large part of the water that fell upon the tree tops was caught there and evaporated without ever coming to the ground.

Surface Drains.

The running of simple water furrows with a plough across those parts of a field that are liable to suffer from moisture is another device of merit, and the system of furrows may, of course, be made as simple or as elaborate as the case demands. Some little trouble must naturally be taken to clear the furrows with a shovel at their points of intersection, and wherever earth has clogged them through imperfect action of the plough. It is to be noted, however, that the purpose of the water furrow, like its construction, is superficial. It is useful to remove any excess of moisture that may fall in a violent shower or come from melting snow, and may consequently be sometimes almost as important on land that is tile-drained as on that which has no artificial drainage.

Land-Beds.

The throwing up of beds or ridges upon moist or springy land is another method, used not infrequently upon the somewhat sloping banks of brooks and ponds, and upon level clay lands also. Here again, as with the open ditch, the level of the ground-water is slightly lowered so as to admit of producing English hay.

It is noteworthy that this idea of raising the level of the soil, without lowering the original level of the water, is a thoroughly natural one. The process is to be seen in every wild swamp or bog where the height of the soil has been increased by the slow deposition of water plants and of the products of their partial decay.

Many of the numerous patches of bog land which have been brought under cultivation in New England are to all intents and purposes land-beds, which have been built up naturally through the growth of aquatic plants. That drains have to be cut after all to depress the level of the water in these natural land-beds is due mainly to the exceedingly retentive character of the vegetable matter with which they have been built.

Land beds were formerly a favorite device of the English farmers. They doubtless mark one stage in the progress of a country towards civilization. The English agricultural writers of a hundred years ago make frequent mention of such "lands," as they were termed, in all sorts of positions. The noted writer, Marshall, argues at length, as a matter of practical experience, that, in seeking to improve cold poachy hillsides in this way, the land-beds should be laid up across the slope of the hill, not up and down, as we usually see them in this country, and everywhere else for that matter. If the beds are thrown across a slope, he says, taking care merely to give descent enough that water may find its way along the interfurrows, none of the rain-water that falls upon the beds will ever have to run any farther than the width of a single bed before it is caught by an interfurrow, even supposing that it falls upon the upper edge of the bed.

But where the beds run up and down a hillside, much of the rain-water which falls upon them will flow over their entire length, from the top to the bottom of the hill, without finding its way into the parallel furrows. Unless the up and down beds be crowned tolerably high at their centres, there will be comparatively little tendency for water to run off sideways into or towards the open furrows. The argument seems not unreasonable in the main, especially when applied to the case of a rainy locality.

Making of Land-Beds.

Land-beds have the merit that they can be cheaply constructed. The making of them is a mere matter of ploughing and harrowing. An approved method is to measure off the land and plough a furrow

at the place which is to be the middle of the bed. Then plough deep furrows on either side of the first furrow so as to "shut it," as the term is, i. e. so as to bury the first furrow; and so go on ploughing the land up towards the centre until the edge of the plot is reached, where open furrows will be left on either side to serve as ditches. The bed is then harrowed and left to itself for the earth to settle, after which the operation of ploughing is repeated. The ditches need to be cleared out, of course, and made to dip so that water shall flow in them, and it is well nowadays to make them wide, with sloping edges, so that the mowing-machine may be driven through them.

Celtic Land-Beds or Ridges.

Beside the comparatively shallow land-beds proper, such as are still used, much higher beds or ridges were formerly in vogue. Until a comparatively recent period, the soil of many districts in England, no matter what the crop, was kept permanently laid up in broad high ridges, which had existed from time immemorial and the purpose of which had even been forgotten. It must still be true, for that matter, that many of these ridges are even now in existence, since it is not easy to destroy one of them all at once without turning up an undue quantity of unproductive subsoil.

These ridges are said to have prevailed particularly in the countries which had been brought under the influence of the Roman civilization. In other words, they were most common in districts that had been longest settled, for the Romans were accustomed to overrun and occupy inhabited places.

As to the size of the ridges, Marshall, writing in 1796 of the Vale of Gloucester, says that the usual ridge of that period and locality was about 8 yards wide and from 2 to 2½ feet high. Some ridges that he measured were 15 yards wide by 4 feet or more high; others were 20 and 25 yards wide, and high in proportion, — so high, indeed, that a horseman riding in one ditch could not see his companion riding in the ditch at the other edge of the bed.

There can be no doubt that the original idea of heaping up the soil in this way was to render some portion of it dry and warm, by removing it from the influence of ground-water; though in the course of centuries the reasons of the practice were so far lost sight of that ridges were built, not only upon clays and the other fine soils which are liable to become muddy and impervious when soaked with rain, but upon all kinds of soils, even in elevated posi-

tions and upon porous subsoils. The ditches between the ridges, moreover, were neglected and suffered to become clogged, often to such an extent that they stood full of stagnant water in wet seasons.

At the close of the last century it was held as a popular opinion in England that the soil had thus been heaped up merely to increase the amount of surface. But it is evident that these high ridges must have had undoubted merit upon retentive soils, and for pasture land in countries liable to much rain. In a field thus laid up there was always a variety of herbage suited to every season, just as there was a variety of soil and of moisture. In a wet season some portion of the ridge would still afford sweet pasturage and dry land for the stock to rest upon, while even in the driest seasons the furrows still remained green.

These ridges have been wholly superseded by systems of underground drains. Their insufficiency was clearly seen by Arthur Young, who, writing in 1769, urged that the ridges should everywhere be ploughed down, and the whole field be hollow-drained.

It is now recognized that the ridges are a characteristic of the husbandry of the Celts, who preceded the present races as occupiers of the soil of Europe. Indeed, the history of the ridges is not a little interesting, as indicating the strenuous and long-continued fight that had to be waged against water in the days when Europe was a mere swamp covered with forests. Some remnants of this style of farming may be seen to-day in the tendency to operate upon wet lands, to dig ditches, to throw up beds, and to handle spades rather than hold ploughs, which is exhibited by Irishmen, both in their own country and in many other localities where they have happened to settle down. Historically considered, the term "bog-trotter" is seen to depend upon truths which might not be fully evident at the first glance.

"*Hilling*" *versus Flat Cultivation.*

In like manner, the practice, still common in many localities, of "hilling up" around corn and potatoes, is a device for keeping the soil dry and warm; so that, even when much water is near at hand, some portion of the roots of the crop may stand in earth that is dry enough to permit air freely to penetrate its pores. It may be said, in general, of the practice of hilling, that it is a relic which has been handed down to us from times and lands of more abundant moisture. Nowadays many good practitioners occasionally

resort to "flat culture," and some writers have urged that hills should be wholly discarded.

In recent experiments on the merits of hills or no hills, made by Gabler, where twelve kinds of potatoes were grown, the first year's trials were decidedly favorable to the hills, which generally gave better yields to the extent of from 10 to 50%. Only in a single instance was the yield on the flat land equal to that of the hilled crops, whence the inference that it is only on light and droughty soils that hills can be dispensed with. But very different results were arrived at on repeating the trials next year, which happened to be dry. Then it appeared that, in respect to the same kinds of potatoes as before, there was a gain in favor of the hills of from 5 to 50% in 8 of the trials, and a loss of from 10 to 50% in 3 of the trials. But in trials with 12 new kinds in the second year the hilled crops gave gains of from 10 to 50% in 6 cases, and losses of from 10 to 20% in 5 cases, while in one case the yield was equal on the hilled and the flat land.

In order to determine what influence hilling may exert upon the temperature of a soil, and upon the amount of water retained by it, Wollny made a number of hills, each of them a foot high and twenty inches broad, with soils of various kinds, and contrasted the temperature of these hills with that of contiguous flat land that was similarly exposed to sun and air. Observations for temperature were made by day and by night, at regular and frequent intervals during the growing season, upon thermometers whose bulbs had been sunk four and eight inches in the earth.

It was found that the earth in the hills retained decidedly less water than was held by the contiguous flat land, especially in the case of soils of good capillary power and of small capacity for heat; and that, in general, during the growing period, the earth in the hills was warmer than that of the flat land. The difference between the two situations was greatest at the season when the daily mean temperature of the soil was at its highest, and it was least noticeable when the daily mean temperature of the soil was at its lowest. But it was only in the summer and in warm weather that the temperature of the hilled earth was higher than that of the flat land. In cold weather, viz. in spring and autumn, and whenever cool weather occurred in summer, the temperature of the hilled earth was lower than that of the flat earth.

It was noticed furthermore, during the growing season, that in

warm weather the earth in the hills was decidedly warmer by day and usually cooler by night than that of the flat land, and that the variations in temperature in the hilled earth were much wider than those in the flat earth. The high day temperature of the hilled earth, as compared with that of the flat earth, is said to have been specially evident on contrasting the average mean temperature of day (6 A. M. to 6 P. M.) with that of night, reckoning from 8 P. M. to 6 A. M. By night, however, except in peaty soils, the temperature of the hilled earth was correspondingly low.

In the morning, the earth of the hills was, in warm weather, usually cooler than that of the flat land; but in the evening it was warmer. Other experiments made to test the influence of varying exposures to sunlight showed that hills running from east to west were warmer by day and cooler by night, and were subject to wider variations of temperature than those ranging from north to south.

Covered Drains.

Beside open ditches, the employment of which is as old as agriculture itself, covered drains of one kind or another have long been used occasionally, and their use has become extremely common of late years in many districts. As long ago as 1652 W. Bligh published a work in which he recommended that drains should be made by putting faggots or pebbles at the bottom of a trench and covering them with earth.

Marshall, the old English agricultural writer, has much to say of covered drains. He describes several varieties. The oldest consisted of three alder poles or larch poles, laid one upon two, so as to form a kind of pipe. Others were formed of bundles of fagots: these lasted a dozen or fifteen years. An excellent drain, said to be more durable than the fagot drains, was made of sods, by scooping out a narrow trench so as to leave a shoulder upon which, and across the water-way, sods were laid grass side downwards, and then trodden firm and close, after which operation the trench was filled with the excavated soil. In case the soil was not firm enough for the shoulder, an artificial shoulder was formed with sods cut square and set firmly on each side of the bottom of the trench, so as to leave a channel 3 or 4 inches wide between them. Marshall commended pebble drains also, but he directs that sods should be laid upon the pebbles to cover them before the earth is shovelled in.

A modification of the old pole drain has recently been described as in use in British Columbia. Trees are split edgeways, and the sections are placed with their narrower part downward at the bottom of a narrow three-foot deep trench. Water runs freely beneath the wood, i. e. between the point of the wedge-shaped rail and the sides of the trench, and, if good hearty timber is selected, the drain will continue to work for years.

Arthur Young in his "Six Months' Tour" describes at some length the very extensive drainage operations of Lord Rockingham, which consisted in first digging numerous open ditches, of suitable depths, and of width proportionate to the original wetness of the land. The larger ditches were left permanently open, but all the smaller ones were converted into covered drains. In some of them capacious rectangular drains were built of flagging stone set against the sides of the ditch, and covered on top with broad flat stones laid across and resting upon the tops of the upright flags. In ditches that were still smaller, oblong flags were set with their lower edges on the bottom of the ditch, and their upper edges resting against each other, so as to form an inverted Λ. Pebbles were thrown in upon these stone conduits, and finally a good depth of earth. Though costly, such drains were doubtless effective and durable. Young says of them: "The improvement by these drains, which last forever, is almost immediately manifest. The summer succeeding the first winter totally eradicates in grass lands all those weeds which proceed from too much water, and leaves the surface in the depth of winter perfectly dry and sound, insomuch that the same land which before poached with the weight of a man will now bear without damage the tread of an ox. In arable lands the effect is equally striking, for upon land that used to be flowed with rain, and quite poisoned by it during winter and spring, grain now lies perfectly dry throughout the year. In the tillage of such land a prodigious benefit accrues from this excellent practice, for the drained fields are ready in the spring for the plough before the others can be touched. It is well known how pernicious it is to any land to plough or harrow it while wet."

This example is interesting, as showing what strenuous efforts were sometimes made to drain land before drain tiles were invented. So too, Fellenberg at Hoffwyl drained his entire estate with fagot or pebble drains in the year 1804.

Drainage by Pricking.

Still another system applicable in certain cases was to bore into moist places with a boring tool, so that the confined water might well up through the opening and flow away. The same boring implement was used also for pricking retentive subsoils, so that the ground-water might drain away into the underlying gravel or sand. Both these operations, however, were of extremely limited applicability, and good judgment, as well as an accurate practical knowledge of the geological structure of the locality, was required in order that they should succeed.

Another method of merit in some special cases, as where an isolated flat or saucer-shaped field is surcharged with moisture, is to dig a simple well or pond-hole, and pump water from it continually, or as often as need be, with wind, or steam, or water power. In this way, a considerable area of land may be drained when the circumstances are favorable.

Drain Tiles.

An enormous impetus was given to the practice of thorough draining by the substitution of bent roofing tiles for the poles and fagots and stones previously employed. A horse-shoe tile was laid at the bottom of a trench with the concavity upward, like an inverted ∩. An improvement on this idea was to put a flat tile beneath the horseshoe, thus: $\underline{\cap}$; and in either case the earth was shovelled back into the trench to bury the tiles.

Short earthen tubes made expressly as "drain tiles" were soon substituted for the clumsy roofing tiles. Taken in section, the commonest form of drain tile resembles the letter O. Such tiles have now for many years been in familiar use in most countries where agriculture is in an advanced condition. Even in this country they are slowly working their way into some districts.

Ordinarily, the drain pipes are simply placed end to end at the bottom of the narrow ditch which has been scooped out to receive them, and the earth is packed down hard above them. The pipes thus constitute a continuous tube, which is laid at such inclination, and so connected with cross or main drains, that the water can flow in it freely and find ready discharge.

Water will run freely in a hollow pipe like this even when the fall is very slight. It is said that, when carefully laid, such drains will still discharge water where the fall is not more than at the rate of three feet to the mile, though in actual farm practice the fall

is of course much greater than this. The ground-water slowly soaks in at the joints of the pipes, and quickly flows away through the hollow tube.

Even the stiffest clays may be dried and made mellow in the course of a few seasons by such pipes laid at a depth of 3 or 4 feet, in frequent rows, from 15 to 30 feet apart. With regard to the soaking of the ground-water into the pipes, it may be observed that it is an exceedingly difficult matter to keep water out of any earthen-ware construction sunk in the ground. The city sewers, for example, built of hard-burnt bricks laid in cement, invariably drain off the ground-water from the territory through which they pass, though no intentional cracks or openings are left in them. Aqueducts built of masonry often act in precisely the same way. Great trouble is commonly experienced when a village grows to be a town, and proceeds to have sewers laid in its streets; for the sewers almost invariably drain many of the wells completely dry, from which the water supply of the inhabitants had been procured. And the trouble is one that cannot readily be avoided, since it is important that sewers should always be laid before aqueducts, lest the increased use of water, due to its presence in unwonted abundance, cause the old cesspools to overflow, and occasion epidemics of disease.

Drought often mitigated by Draining.

Far better results have been obtained by the use of hollow drains on clayey soils than could have been anticipated. It is plain enough that great advantage will be gained when wet lands are drained, in that they can now be ploughed and harrowed much earlier in the spring than was possible before, and that, in consequence of this power of tillage, the farmer will have much greater freedom on the drained land for planting his crops at appropriate seasons. It is evident, moreover, that it might easily happen that, through unfavorable weather, undrained land could not be planted at all until after the proper time for planting had gone by; or, supposing that the land had been planted, rains might set in, either in spring or autumn, and so clog the pores of the soil that seeds could not germinate or young plants continue to live in it.

But it could hardly have been foreseen, though now found to be true of many clayey soils, that the ground, beside being made warm and sweet and mellow when thoroughly drained, is actually much less liable to suffer from drought than it was before. The depth

of soil fit for roots to penetrate is so much greater in drained land than in that which is undrained, that the plant provides itself with better apparatus for taking up water. More than this, the capillary movement of water is freer in the drained soil; and the power of such soil to absorb rain and dew is increased. In order to the best results in this sense, drains should be laid deep enough to admit of deep ploughing above them.

Something more will need to be said in another place of the action of air that is introduced to the soil through the drain pipes. It can be conveniently discussed under the head of Tillage.

Tile Drains better than Pebble Drains.

Tile drains are almost always much to be preferred to the rough pebble drains which are still clung to in some parts of New England. The tile drains are often cheaper than the other kind, to begin with, and they are vastly more efficient. The open pipes offer a ready flow and outlet for the ground-water, as if they were a natural brook, while in drains full of stones the flow is hindered and checked at every turn. Moreover, the soil immediately above the narrow tile drain has access to water, and does not fail to draw up an abundant supply of it by force of capillary attraction. Above the broad ditch of stones, on the contrary, there is apt to be an arid strip, where the plants, being cut off from water, die of thirst.

The argument so often heard in favor of the pebble drains, that the farmer must in some way disembarrass himself of the stones upon the surface of his fields, is apt to be a specious argument. Such pebbles had better be thrown away, or into heaps, or into bog-holes, for the chief cost of a tile drain must always be the labor of excavating for it.

One word needs specially to be said to New Englanders with regard to the inapplicability of tile drains in soggy peat meadows. When the water is drained out from such spongy lands, the earth settles upon itself to an enormous extent, and so tends to bring near to the surface any tiles which may have been laid in the bog, no matter how deeply. But when thus raised up, as it were, the tiles can no longer do efficient service, and they are liable withal to be struck by the ploughshare.

As a rule, the process of draining wet, boggy peat lands should be gradual. Frequent open ditches, that may occasionally be deepened in the course of years as the land subsides, should precede the tiles, which may eventually be put in deeply beneath the bottoms of the

ditches when the land has become consolidated. It is in such soft and mucky places as this that "collars" (i. e. rings which encircle the joints of the drain) have significance, as a means of holding the pipes in place. But collars are usually quite unnecessary when tiles are laid in stiff clays.

Drain Tiles are not stopped up by Roots.

Nothing illustrates better the mode of action of tile drains than the fact that, when properly laid, without "dips" or depressions, the roots of crops rarely stop them. But why is this? Simply because the roots of agricultural plants have absolutely no inducement to enter the hollow pipes. At the times when water is actually flowing through the drains, the soil around them is surcharged with moisture, and the crop has more water at its disposal than it can use. But when the drain is not flowing, there is no water inside it, and nothing to attract the roots. The moisture is all now outside the pipes, — below them indeed, — and there, in point of fact, the roots go in search of it.

A mat of rootlets outside the tiles is common enough, but they have no call to enter the pipes, unless perchance the pipes have been laid improperly, so that there are depressions in them filled with water or with moist silt. Of course, in case one of the lines of pipes should serve as an outlet for some actual spring, then it would be an aqueduct, and might contain water when the soil around the pipe was comparatively dry. In this event roots would be liable to enter the pipe, but instances such as this are exceptional. Cases are on record, however, where the fibrous roots of mangolds have completely filled up and stopped such aqueduct pipes laid two or three feet beneath the surface of the soil.

Drains warm the Land.

The influence of drains in warming the soil is very decided, particularly in the spring of the year. The large amount of water which then drains away from the land through the pipes, instead of evaporating, represents an amount of heat equal to that which would have been consumed in effecting the evaporation. The moment an attempt is made to calculate the quantity of heat which would be required to evaporate the surplus water from an acre of land, figures are encountered which are simply enormous. Besides the immense amount of heat required for evaporating water, that is to say, for changing liquid water to the vapor of water, there is another reason, as was said before, why wet land must always be cold

land; viz. because the caloric capacity or specific heat of water itself is larger than that of any other solid or liquid substance. More heat is required in order to warm up a given weight of water than would be needed to warm a similar weight of soil. More heat is used up, so to say, in raising the temperature of the water from one thermometric degree to another, than would suffice similarly to increase the temperature of the soil itself. Oemler has determined the specific heats of several kinds of soils, as follows. All the samples of soils were completely dry.

	Specific Heat.		Specific Heat.
Water	1.0000	Loam	0.1496
Moor earth	0.2215	Pure clay	0.1373
Humus	0.2086	Fine sand	0.1048
Sandy humus	0.1414	Coarse sand	0.0968
Loam rich in humus	0.1662	Pure chalk	0.1848
Clayey humus	0.1579		

Some of these figures are specially interesting, notably those which show how small a capacity for heat is possessed by sandy soils, and how much greater is the power of clay and humus and chalk.

In so far as agricultural soils are concerned, it does not help matters much that water, when once it has been warmed, holds heat forcibly, as is seen familiarly in the comparatively slow cooling of the water of the ocean and of lakes at the close of summer.

An excess of water in the soil may hinder the absorption of heat in another way, viz. because water is a very poor conductor of heat. When water is warmed at its surface, only very little, if any, of the heat can be transmitted downward. The soaking of warm rain-water into a drained soil has, however, a marked effect in elevating the temperature of the soil. It is evident that, in soils naturally so porous that rain can readily soak into them, the warmth brought from the air by this water and that taken by it from the surface of the land will be imparted to lower layers of the soil, often to the great advantage of the crops; and the same thing has been found to be true of soils that have been made porous by draining them.

The English engineer Parkes observed that a natural bog had a constant temperature of 46° F. at depths between 12 inches and 30 feet, and a constant temperature of 47° at a depth of 7 inches; whereas in a portion of the bog that was drained and tilled a thermometer sunk to a depth of 31 inches indicated a maximum temper-

ature of 48½°. In the tilled land the temperature rose to 66° at a depth of 7 inches after a thunder-storm, and on the average the temperature was 10° higher at a depth of 7 inches than it was in the natural bog. By a rain in the middle of June, the temperature of the tilled land at a depth of 7 inches was raised 3½°, though it fell again half an hour after the rain had ceased, because of the rapid evaporation of water from the surface of the soil.

Practical men justly attach much importance to all processes of culture which tend to make soils warm and mellow. It is not alone the warmth of the air, but that of the soil also, which promotes the growth of crops.

It has been officially determined in Prussia, that the snow melts in that country a week earlier, on the average, upon drained than on undrained land similarly situated. It is notorious, moreover, that the advance of vegetation is peculiarly rapid upon drained land. Parkes has given the following illustration of the cooling effect of evaporation. Suppose, he says, that the yearly rainfall is 30 inches; this would amount to 108,900 cubic feet, or 3,038 long tons, to the acre per annum; or to 298 cubic feet per diem, i. e. to 8⅓ tons, or 18,647 lb., for each day in the year.[1] To evaporate such an amount of water, 24 cwt. of coal a day, as ordinarily used under steam boilers, would be needed, or 1 cwt. per hour, per acre throughout the year.

According to Gasparin, observing in France, 82% of the water that falls upon an acre of land in the course of a year, or 5,326,000 lb. of water, go off by way of evaporation. Whence Barral has computed that an amount of heat is consumed equal to what would be disengaged by burning 240 tons of coal.

The amount of water actually present in a soil has often a preponderant influence on the temperature of that soil; and the different kinds of soils, when once thoroughly wet, will naturally be very much alike as to their power of absorbing and retaining heat, for the absorption of heat by the water as it passes from the liquid to the gaseous state in the process of evaporation will be the chief cause of refrigeration. Differences of temperature as great as 10° or 15° between wet and dry soils, due to this cause, have often been noticed.

The cooling influence of water is shown very distinctly in experiments made to test the effect of dark-colored substances upon the

1 One inch of rain on an acre of surface equals 27,154 U. S. gallons, or 862 barrels. — S. W. Johnson.

temperature of soils. Wollny found in effect that the influence of color on temperature diminished in proportion as the amount of water in a soil was larger, and that it might be entirely overpowered in cases where the presence of an abundance of humus, or some other circumstance, was favorable for the accumulation of large quantities of water. The darker the soil, however, so much the more strongly may water depress its temperature, since the heat absorbed by the colored material enables just so much more water to evaporate.

Although there are hundreds of thousands of acres in this country that could be improved by means of tile drains, the fact must not be lost sight of that current statements regarding the general or universal good effects of draining apply far more forcibly to damp countries, like England and North Germany, than they do to most parts of the United States. They apply also to districts where the soil is extremely fine, as in some of the Western States, as well as to stiff clay soils. Since the main province of drains is not to carry off a sudden fall of rain, but to relieve the land from any excess of water which may soak into it from any source, and to promote the circulation of air and moisture in the soil, their purpose will naturally be better accomplished in countries where light drizzling rains abound, than in our own land of heavy showers.

In countries where the land is liable to be frequently moistened at seasons when the operations of tillage and seeding need to be attended to, drains are often indispensable. But in this country rains are not particularly frequent. They are apt to be heavy, and are often of such character that much of their water flows off the surface of the land. It is true that a larger number of inches of rain falls here in the course of a year than in England and Germany, but the character of our showers is very different from that of theirs. The fact must be remembered also, though often lost sight of by over-strenuous advocates of drainage, that many of our leachy, hungry uplands of "drift" gravel are far too thoroughly drained already. It is true withal, that in America much land is so cheap that it might often be better policy to buy an additional new field rather than to spend money in improving an old one.

For sanitary reasons the draining of fields about houses is not infrequently a matter of importance everywhere. Excellent American books on Drainage are those of French and of Waring.

CHAPTER V.

TILLAGE.

THE purposes of tillage are twofold. First, to improve the texture of the soil, in the mere mechanical sense. That is to say, to stir and loosen the soil so that the roots of plants may readily pass through it; that air and water may freely enter it; and that water may move through it easily, while at the same time a certain amount of moisture may be retained, and indeed be rather firmly held by it. Secondly, so to alter the position and condition of the particles of which the soil is made up, that changes in the chemical composition of these particles may be brought about by the action of air and water, and the microscopic organisms which act as ferments.

Some soils are so stiff and heavy that neither roots nor water can freely penetrate them. Others are too light and open; and the particles of some are so very finely divided that special care must be taken lest they run to mere mud at every fall of rain, and thereafter bake hard.

In all these cases great improvement may be made by tillage, through mere alteration of the mechanical condition of the land. But it is manifestly impossible to disturb the soil in any way without bringing its particles into new relations with the air, and commingling anew the various substances proper to the soil, together with whatever fertilizing or alterative materials may have been added to the soil or have been grown upon it. Hence, as a matter of course, chemical changes are induced in all operations of tillage, as will be insisted more in detail hereafter.

It is true also, that biological changes are induced by the operations of tillage; for, as is now well known, a variety of microscopic organisms, some of them useful and others hurtful in respect to the growth of plants, have their being in agricultural soils. It is known, too, that the growth of some of the useful kinds of these microdemes is most rapid in soils that have been brought into a good condition of porosity, so that air and moisture may have free access to all their particles.

Importance of Good Tilth.

It will be proper first of all to describe some of the essential conditions in respect to standing room which plants require, and to dwell upon the enormous influence which good tilth must necessarily exert upon the growth of crops.

A soil should be firm enough to afford proper support to the plants that grow in it, and yet be loose enough to allow the most delicate rootlets to grow without hindrance. Its condition should be such that air may freely enter the pores, and that any undue excess of water may drain away readily, and yet the texture should be so close that much of the rain-water which falls upon the land may be retained and held permanently, or until the growing crops have put it to use. Nothing illustrates more forcibly the sentiments of practical men upon this point, than the care they take to prepare a mellow seed-bed whenever an important crop is to be grown. There are in fact very good reasons why the soil should be made mellow before seeds are sown in it. For not only is it necessary that some air shall gain access to a germinating seed, but the points of the roots of young plants that are just starting into life are so soft and feeble that they can only make progress in those directions where they find pores in the soil. Every hard obstacle which such roots encounter tends to distress the plant: it is a hindrance to proper growth, and may even cause the young plant to perish in case the roots cannot find a way of working around it.

So too with more mature plants. The soft points of growing roots do not habitually bore through solid clods or firmly impacted earth, but they push into any open spaces which they may happen to encounter between the lumps and particles of which the soil is made up. Hence the importance of tilling the soil to increase the number of these interspaces. A soil that is in good tilth, and mellow, presents innumerable openings and channels for the passage of the rootlets in this way.

Roots must have ample Room and Freedom of Motion.

Practical men lay special stress also upon the importance of thorough tillage for "root crops," such as beets, carrots, and rutabagas. They direct that, in preparing for these crops, the land should be ploughed and harrowed repeatedly to make it mellow and friable, and urge that it is useless to try to grow roots unless the land can be well prepared beforehand.

A familiar illustration of the importance for roots of open spaces,

which they may enter, — of air, moisture, and good drainage, — is seen in American greenhouses in the use of very small flower-pots for growing cuttings after they have been "started" in a propagating bed. As compared with the amount of earth that is contained in these little pots, there is presented a very large inner surface of porous earthen-ware, and the roots insinuate themselves between the earth and the inside of the pot, where they find room for their development, while an abundance of air comes to the roots through the porous ware, either directly or to replace the water exhaled from it. There is little chance withal that so small a volume of soil can become much impacted.

Roots are developed by Young Plants.

The natural tendency of roots is to grow downwards, when the soil is in fit condition to receive them, and to grow with surprising rapidity so long as the plant is young.

Hellriegel found upon barley plants that had but a single leaf some roots that were 9 or 10 inches long; on plants whose second leaf had begun to unfold there were single roots 20 inches long. On a barley plant one month old he found some roots that were three feet long.

So too, buckwheat a fortnight old that was beginning to develop its second leaf had roots nearly a foot long, and so had clover plants that were showing their fifth leaf. Pea plants a month old that were 10 to 16 inches high had some roots that were 13 to 17 inches long. These figures, it will be noticed, have no reference to the total length of the roots, as obtained by adding together the lengths of all the roots of a plant. They refer only to single roots, which had attained the lengths above stated in garden loam under favorable conditions.

Hellriegel found that barley plants ten days old in their third leaf had 42 lb. of dry matter in their roots for every 58 lb. of dry matter in the leaves and stem. In plants a month old, at the time of shooting, the relations were 29 in the roots to 71 in the leaves and stem; while in ripe barley plants there were less than 8 lb. of dry matter in the roots for 92 in the leaves and stalks. With oats, the relations were 24½ : 76, 17 : 83, and 13 : 87 of dry matter in the roots to that in the stem and leaves when the plants were shooting, in blossom, and ripe, respectively.

In the chapter relating to Rotation of Crops examples will be given of the distribution of the roots of various crops in soils of different characters.

Roots strive to develop Symmetrical Forms.

In general, it may be said that just as any obstruction above ground that interfered with the symmetrical development of the branches of a tree would hinder the profitable growth of the tree, so any impediment or injury to the roots of plants that impairs their useful development will lessen the amount of crop to be harvested. The analogy is specially close in respect to the crowding of one plant by its fellows, as when too many plants are permitted to grow in a given space. In such case, the roots of the different individuals interfere with one another very seriously, and the growth of the crop is apt to receive even a more emphatic check than would be occasioned by the crowding of its leaves and branches above ground. But the better the land has been tilled, so much the more useful root space will it contain, and so much the larger will be the number of plants that can be grown upon a given area without distressing one another.

It is to be observed that the leaves and branches of plants have naturally a much better opportunity to unfold than the roots can have. For the air offers no resistance to their development in any direction, while the soil must necessarily present obstacles at every turn to interfere with the progress of the rootlets.

The power of obstructions to hinder the growth of roots is well illustrated by some experiments of Hellriegel, where peas and beans were grown in moistened sawdust, some samples of which had been impacted and others not. When the sawdust had been strongly compressed, it was noticed that the development of the roots of many of the plants was greatly impeded, and that many of the taproots in particular were arrested, or even destroyed.

Many Kinds of Plants need abundant Standing Room.

One prime purpose of tillage is to diminish such interference of the roots of crowded plants, in so far as this can be done economically. Both deep tillage and drainage must manifestly help to increase the amount of room useful for the growth of roots. The importance of abundant standing room is familiarly illustrated by root crops, such as beets, carrots, and rutabagas. These crops are seldom or never sown excepting on well-tilled land, and it is noticeable, when care is taken to thin out the rows properly soon after the young plants have started, so that plenty of room shall be left between each individual plant, that the crop will prosper, and that fine large roots will be secured. But if the plants are not thinned,

i. e. if they are permitted to crowd one another unduly, they suffer very much, and few of them will grow to a large size.

Boussingault measured the amounts of space that are habitually allotted to various plants by practical men in the garden culture of Alsatia. He found that each bean plant has at its disposal 57 lb. of earth, a potato plant 190 lb., a tobacco plant 470 lb., and a hop plant 2900 lb. These weights correspond very nearly with 1, 3, 7, and 50 cubic feet respectively. As contrasted with the results of scientific experiments made under conditions which permitted the soil to be kept constantly in good tilth, these measurements go to show how very far from theoretic perfection the operations of field tillage must be, even at their best.

This question of standing room, or rather the influence exerted by varying amounts of soil on the growth of plants, has been carefully studied by Hellriegel in two distinct ways, and some of his results may well be cited as illustrating the vast importance of tillage for the success of crops. They fully support the common conception that all things are possible in a deep soil kept in good tilth and well watered. He first filled a large number of glass jars of four different sizes with sifted garden loam of good quality, and grew pairs of plants of various kinds in these jars in such wise that each kind of plant could be tested as to the freedom of its growth in jars of all the sizes. The idea was that the amounts of earth in the jars should be to one another as 1 : 2 : 4 : 6, and that the absolute weights of soil should be 7, 14, 28, and 42 lb. respectively. The soil used was known to be rich enough for the growth of maximum crops; it was kept constantly moistened to good advantage, and all the jars were kept out of doors in fair spring and summer weather, being set on a railway carriage which could be run under cover in case of storms.

In the course of three or four weeks after the beginning of the experiment, it could be seen that all the plants in the larger jars prospered better than those in the smaller, and that the plants the root room of which was restricted could not keep pace with those which had an abundance of earth at their disposal.

It was found to be true of clover, barley, buckwheat, peas, horse-beans, and lupines, that the plants formed regular series or gradations in consonance with the varying sizes of the jars in which they were growing. That is to say, each individual plant was larger in accordance with the amount of ground which had been allotted for its

own exclusive use. It was found also, that the weights of the crops harvested varied much in the same proportion as the amounts of earth in which they had grown.

As Hellriegel puts it, it could be truly said that the amount of crop harvested was practically in inverse proportion to the sum of the mechanical hindrances to their development which the roots had encountered. He urges that the roots of plants do not naturally form a chaotic tangle, but strive always to grow in harmony with a symmetrical plan, which is just as definite and well proportioned, and as characteristic for each particular kind of plant, as are the forms exhibited by the stems, boughs, and leaves of the plant, above ground. Anything which works seriously to prevent the original plan as to root structure from being carried out will be seen to affect the development of the crop as well.

In the case of the pot experiments just now cited, it was found that the mass of roots was much larger in the larger jars than in the smaller, though somewhat less compact.

The Weight of a Crop may depend on the Amount of Standing Room.

Some curious parallelisms between the amounts of standing room and the weights of crops produced were noticed. Thus, with red clover, while the amounts of earth in the jars were as 1 : 2 : 6, the dry crops were 1 : 2.4 : 5.7. In the case of peas, quantities of earth related to one another as 1 : 2 gave dry crops equal to 1 and to 1.6 respectively, and similar coincidences were noticed in respect to beans and barley.

Even in volumes of earth so small as those employed in these experiments, it was easy to destroy the tilth of the soil by improper treatment. For example, in case air-dried loam was poured into the jars and left to lie loose until after the time of planting, the mechanical condition of the soil was damaged to such an extent when water was then poured upon it that the crops were seen to suffer. This effect was more conspicuous in the larger jars, and seems to have been due to a partial puddling of the earth. The trouble was avoided subsequently by compressing the dry soil slightly, layer by layer, when it was placed in the jars.

Harm done by Crowding.

By another, and still more interesting, series of experiments, Hellriegel proved that any considerable number of plants grown together in large jars did no better, individually, than one or two plants grown in a small jar. Indeed, generally speaking, they did not

grow as well. That is to say, the bad effects of crowding may be shown as conspicuously by growing an undue number of plants together in a large volume of earth, as by allotting a small volume of earth to a single plant, or to a pair of plants.

In these trials 1, 2, 3, 4, 6, 8, 12, 16, and 24 barley plants were grown in jars of three different sizes containing respectively about 4, 11, and 28 lb. of garden earth. The plants were fed and watered, and cared for as before. It was calculated that in the large jars that carried 3 and 4 plants, in the medium jars that had 3 plants, and the small jars that had 2 plants, the crops stood about as thickly as barley does usually in field culture; but that the larger jars, with 8 or 12 or more plants, were crowded. So were the small jars that carried 4, 6, and 8 plants, while the jars which had only a single plant, and most of those that had two, supplied from two to four times as much space as is ordinarily allowed to barley plants in the field.

The effects of the crowding were soon seen in the smaller size of the plants both in the small jars and in the jars that contained many individuals, and these differences were more and more clearly defined as the plants became more fully developed. The growth of the single plant in the largest jar is said to have been marvellous. There seemed to be no limit to its power of stooling. When the first ears of grain were ripening, young shoots were still being thrown up from below. This plant produced no less than fifteen stalks that bore ears, and some of the ears were of gigantic size, filled with superb grain. In the large jar that had two plants, the luxuriance was already less marked, though one of the plants had eight stalks that bore ears and the other had six. In the other jars the tendency of the plants to stool decreased according as they were more crowded; the large jar that had 24 plants showed hardly a trace of it. The crowded plants ripened also sooner than the others.

In contrast with the enormous single plant in the large jar that contained about 28 lb. of earth, the 24 plants in the medium-sized jar that contained 11 lb. of earth were noteworthy. They were perfectly healthy, and to all appearance normal, though comparatively small. Each of these mature plants weighed when dry from 600 to 1200 milligrams, and bore from 10 to 22 seeds, while the single plant of the large jar weighed over 33,000 milligrams and bore 636 seeds.

All the experiments went to show that it is easy to determine beforehand how large a well-fed and well-watered plant shall grow by limiting the volume of earth which stands at its sole disposal. It is noticeable withal, that, where the supplies of food and water are ample, an undue excess of standing room may lead to a not wholly advantageous luxurious habit of growth, somewhat in the same way that an excess of manure might. Hence it may be said that a certain amount of crowding is necessary in order to the best utilization of the space which has been devoted to a crop.

Indeed, the significance of tillage might be very well illustrated by a reference to the different numbers of plants that are grown to the acre of land in new and in old countries. Washington wrote long ago, in a letter to Arthur Young, "An English farmer must have a very indifferent opinion of our American soil when he hears that an acre of it produces no more than from 8 to 10 bushels of wheat; but he must not forget that in all countries where land is cheap and labor is dear the people prefer cultivating much to cultivating well."

In the same sense, Boussingault tells of a field near Pampeluna where he saw wheat growing in isolated tufts, all extremely vigorous and very heavy in the ear, though the ground had had very little preparation. A yield of from 60 to 80 times the seed was expected, and the crop was regarded as a profitable one, though it could not have amounted to more than 7 or 8 bushels to the acre. Whence it appears that a large area of ill-tilled standing room may suit each individual plant as well as a much smaller area that has been subjected to tillage.

Some of the results obtained by Hellriegel are given in very condensed form in the following table.

No. of Plants in a Jar.	Large Jar. (12½ kilos earth.) No. of Ears.	Weight of Crop. Grain. grm.	Total. grm.	Medium Jar. (5 kilos earth.) No. of Ears.	Weight of Crop. Grain. grm.	Total. grm.	Small Jar. (1.7 kilos earth.) No. of Ears.	Weight of Crop. Grain. grm.	Total. grm.
1	867	14.82	33.16	381	9.11	17.27	228	4.05	7.70
2	723	15.12	31.31	465	10.13	19.69	228	4.65	9.34
3	765	13.78	31.22	453	10.64	19.86	246	4.44	8.54
4	984	18.79	39.50	480	10.96	20.42	291	4.35	9.40
6	1050	18.53	38.93	480	11.87	21.78	177	4.50	8.55
8	1170	20.23	41.82	468	12.77	22.53	246	5.32	10.03
12	1101	20.81	41.56	471	11.96	21.37	...	...	...
16	978	20.50	41.18	546	11.92	22.32	...	...	...
24	1062	21.07	41.65	591	12.41	24.42	...	...	...

It is very remarkable how little difference there is, in one and the same kind of jar, between the crops obtained from different numbers of seeds. But it will be noticed in each of the three series that there is a line or limit below which the crop diminishes in proportion as the number of plants is larger, and above which the yield does not increase appreciably on increasing the number of plants. In the series of large jars this line will be found to lie between the jars that contained 6 and 8 plants. Here it will be seen that 8 seeds gave a crop as large as that obtained from 24 seeds; but the 8 seeds gave little more crop than 4 seeds, and each of the 8 plants was only about half as large as the plants in the 4-seed pot. In other words, the volume of earth in the large jars (some 28 lb.) can be utilized as completely by 8 plants as by 24, but cannot be fully utilized by less than 6 or 8 plants; whence the inference that a given volume of the earth could afford to a plant only a certain definite amount of useful space, and that, when this space is once fully occupied, the growth of the roots must cease. But since the production of stalks and leaves and grain stands in a definite relation to the number of roots, and depends upon this number or quantity, the crop will naturally suffer whenever it is diminished.

In the medium-sized jars that contained 11 lb. of earth, 4 to 6 plants made about as good use of the soil as any larger number; and in the small jars containing about 4 lb. of earth, 1 or 2 plants gave almost as large a yield as any larger number.

All these experiments enforce the lesson, that one fundamental advantage derivable from tillage is the removal of mechanical impediments to the symmetrical development of the roots of crops, and they go to show that an abundance of root space provided with a proper supply of water may often be more important on the whole than heavy manuring. Hellriegel found, in fact, that, no matter how much or how many fertilizing substances were applied to the soil, it was impossible for plants to make proper use of these materials unless they had adequate standing room. Whenever the volume of earth was restricted, he soon came to a limit beyond which it was impossible to increase the crop by giving it more food: the thing then necessary to be done was to provide more room for the roots, and so remove or avoid the impediments which had previously hindered their proper development.

The Old Belief that Tillage may serve instead of Manure.

So important is thorough tillage for the growth of good crops that it has sometimes been argued that, if the operations of tillage could but be made perfect, manures might be dispensed with.

A noteworthy instance of this belief is recorded in the history of English agriculture, in respect to the famous system of horse-hoeing husbandry, advocated by one Jethro Tull (1680–1740), which attracted no little attention in its day. Having noticed that the growth of plants is greatly favored by cultivating them in rows, and frequently stirring the soil between and around them, even when this soil had been left unmanured, Tull jumped to the conclusion that manures are unnecessary; that finely pulverized earth and moisture are all-sufficient, and that mechanical operations competent to effect the stirring may be substituted in all cases for manures and systems of rotation. Carried away by this conception he pursued it with devotion, to the ultimate injury of himself and his disciples.

It is said that Tull's hypothesis was in so far supported by his practice that he was enabled to obtain twelve successive remunerative crops of wheat from the same land without manure by repeatedly ploughing and cultivating it. But the soil of his farm was a deep loam, such as is often found in countries which have long been carefully cultivated, and it was at last practically exhausted. The weakness of the argument would doubtless have been sooner discovered by an experimenter placed upon the gravel of New England.

The experiment of Tull was really one of considerable value, for it teaches a highly important lesson as to the real significance of tillage; and by its very failure it illustrates and reimpresses the importance of manures and the merit of systems of rotation. It probably led in its day to the diffusion of much clearer conceptions as to the action of manures and the modes in which soils are formed than had been held previously.

It is still usual to speak of Tull's experiment as of a failure which must necessarily have come to pass sooner or later if his conception were persisted in and carried out practically; and it is doubtless true that the chief influence which the experiment has exerted upon the progress of agriculture depends upon the limitations to which the conception is really subject. But strangely enough it has been proved in recent years that Tull's idea as to the

sufficiency of tillage is after all correct in the main as regards soils such as that upon which he operated.

The Lois-Weedon System of Tillage.

The system was revived in England some years since by the Rev. Mr. Smith of Lois-Weedon in Northamptonshire. Operating upon a clay soil, Smith produced large wheat crops continuously on the same land for a long series of years without manure, by simply laying off his fields in strips five feet wide and growing the crop in drills on alternate strips in successive years. The vacant strips were spaded and ploughed deeply and frequently, so that through disintegration of the soil and absorption of matters from the air plant-food enough for the next year's crop was procured.

By this plan of culture, Mr. Smith raised the yield of wheat from 16 bushels per acre to 34 bushels (as the average of many years), without using a particle of manure. His experiment has shown clearly what may be done by tillage alone in case a proper relation is maintained between the amount of crop and the area of land devoted to the crop. Tull not only attempted to grow too many plants upon each of his fields, but he failed to plough deeply enough. One of the rules of his practice, for example, was, "Never plough below the staple."

But it is evident from common experience, that tillage alone, no matter how deep and frequent, cannot wholly, i. e. cannot economically, supply the place of manure, unless the soil be exceptionally good and deep, and readily decomposable. It is now known perfectly well that there are several conditions necessary for the growth of crops, such, for example, as an abundance of fit food, an adequate supply of moisture, and proper standing room, and that each one of these requirements is just as necessary as either of the others; though it is true enough that one or another of them may sometimes be supplied naturally upon a given field in such fulness that the farmer feels no need of taking thought for it, and is at liberty to devote himself more particularly to the task of supplying whatever may be most conspicuously lacking.

The Lois-Weedon system of tillage, though specially interesting as an illustration of the advantage of giving plants an abundance of standing room, well prepared for the development of roots and for the storage of moisture, has in addition enough resemblance to the old method of "summer fallows" to be mentioned in connection with them. As will be explained under Rotation of Crops, a

fallow field was a field left bare and without any crop. But evidently such a field is much the same thing for a whole farm that the vacant strips of Mr. Smith are for a single field. The fallow fields, like the vacant interspaces at Lois-Weedon, were repeatedly ploughed and harrowed to fit them for next year's crop. That is to say, they were thus ploughed and harrowed by the best farmers, so that various processes of decay and disintegration within the soil were hastened, and many constituents of the earth that were previously lying there inert and useless became available for feeding crops.

Disintegration of Rocks as related to Processes of Tillage.

Having in mind the vast importance of the disintegration of rocks for supplying plant food, some writers have argued that tillage may justly be regarded as an extension and continuation of the natural processes by which soils are produced out of the original rocks. Undoubtedly it is interesting and instructive to look upon this side of the matter, though it can only present a partial and limited view of the subject.

As is well known, most soils are composed of more or less minute fragments of rock, broken and corroded beyond all hope of recognition. If the original rock were limestone, a calcareous soil will naturally result from its disintegration, and if the rock happened to be rich in fossil remains a specially fertile soil may be formed; from feldspathic rocks clays are derived; while from silicious rocks come sands and gravels in infinite variety. Both sands and gravels sometimes consist of grains of nearly pure silica, though usually they contain many fragments of broken rocks and minerals which are very far from being wholly silicious.

Speaking in general terms, it may be said of cultivable soils, that they consist essentially of sand and clay, often admixed indeed with some small portions of the remains of organic matters. The sand may have come directly from the disintegration of rocks where it lies, though throughout the Northern United States, as in the vicinity of Boston, for example, it has almost always been transported by water, if not by ice; while clay is usually a product of disintegration which has been succeeded by processes of washing with water and subsequent deposition of mud therefrom.

Generally speaking, mixtures of sand with a moderate amount of clay and a due proportion of humus are well fitted for agricultural purposes. When the proportion of sand or gravel is unduly large,

the soil may still have merit in that it is easily tilled, and that it admits of being tilled at almost any time when it is not actually frozen; but unless they happen to be favorably situated as regards the ground-water, these light sandy and gravelly soils can hardly ever be fertile, because they cannot hold rain-water in sufficient quantity or long enough either to supply the needs of crops or to enable the crops to fully profit by the manures that are applied to them.

When clay is in excess, on the other hand, the soil is difficult to till at any time, even when it is dry, and especially when it is wet. Such land is called "heavy." Clays can only be tilled with advantage at those times and seasons when they are "in fit condition," as will be explained directly. In a wet season it may happen that there will be very few days when clay can be properly worked. It has been said in England, that while two horses may till 80 acres or more of light land in a year, they can seldom do the tillage of 60 acres of clay. Hence the clays, though often fertile and very productive when well managed, and devoted to the comparatively few crops for which they are adapted, are less generally esteemed than the loams proper.

Decomposition of Rocks in Place.

In New England, where a large proportion of the surface of the country is covered with the deposit of loose water-worn and ice-worn stones, — which the older geologists called "drift," and which has been brought by moving ice from a more northern position, — and where even the clays have been accumulated and transported by glacial action, it is not often that there is any good opportunity to recognize that gradation from soil to rock which is the general rule in the formation of soils all over the world, and which may be observed abundantly in central Europe and in many other countries.

In many localities a tolerably accurate opinion as to the character and fertility of any given soil may be formed by noting the source from which the soil has been derived and the manner of the derivation; i. e. the character of the parent rock, the degree of its disintegration or erosion, and the distance to which some of the products of disintegration have been transported. A soil that has resulted from the disintegration of a feldspathic rock in place may fairly be expected to be a fertile soil, at least in respect to potash; and so may a clay which has manifestly been derived from neighboring granite. In both these cases the soils would naturally be

expected to be "strong," and to have considerable power of holding water. Alluvial lands which have been formed by the washing down or deposition of finely divided products of disintegration from a variety of rocks are often particularly fertile and well balanced as to their chemical composition.

Evidences of Disintegration are specially Strong in some Hot Climates.

In the Southern States of this country soils are common enough which have resulted from the decomposition of rocks in place; and it is noteworthy that the decomposition of the rocks in southern latitudes seems to have proceeded much farther than is the case at the North, and that the soils are consequently deeper. In Alabama, for example, in the region of granite and other primitive rocks, it is said to be not uncommon to find, in railway cuttings and wells, soils of disintegration 30, 50, or even 70 or 80 feet thick.

The warmer climate of the South seems to favor this deep-seated disintegration, and it is true that comparatively warm water there percolates the soil throughout the year, and that carbonic acid is incessantly generated from the decay of organic matter. That is to say, some of the agents which work for disintegration are incessantly active. It is possible, of course, as some geologists have urged, that the absence of glacial action at the South has left many examples of old disintegrated rocks in place, while at the North the rotten hills have been planed off by ice or swept away by water.

It is notorious, for that matter, that the causes of deep-seated disintegration, such as is often exhibited by great masses of rocks that contain ferrous silicates, are not clearly understood. Boussingault in one instance traced such disintegration to a depth of more than 300 feet in a mine worked in syenitic porphyry. The deep Southern soils just mentioned, resulting from the decomposition of granite on which they repose, are commonly of excellent quality.

Other Examples of Rock Disintegration.

In the fertile hilly region of Saxony, where the soil proper is a fine deep loam, wellnigh free from tangible stones, there will often be found a subsoil of angular fragments of gneiss or schist resting undisturbed upon the rocks of which they were once a part. At the mouths of mine pits in the still higher Saxon hills great heaps of artificial fragments of the same kinds of stones may be seen, in all stages of disintegration and decomposition.

Many of the older heaps, which date by centuries, have become

covered with soil enough to support grasses and other conspicuous plants, — sometimes even small trees, — while patches of moss are only just beginning to grow upon the rock-heaps of recent years.

The soil of the famous Constantia vineyards, near Cape Town, at the Cape of Good Hope, is a coarse feldspathic gravel resting immediately upon the granite, through the disintegration of which it has been formed.

Similar effects are conspicuous in the volcanic regions of many hot countries. After a hardened stream of lava has been exposed to the weather for years, it becomes corroded sufficiently for mosses to gain a foothold, and upon the ruins of these mosses other plants take root, so that, in spite of the denuding action of wind and rain, the lava becomes covered, in the course of years, with a film of soil proper for the growth of many plants. This process of disintegration never stops. It goes on incessantly, even when the rock has become covered with a deep fertile soil bearing a dense forest.

The same agencies are at work all around us, upon every kind of rock, and upon every soil, though in a country so recently devastated by fires as New England it is easier to observe the beginning of the process of disintegration than to trace its results. The fires of the early settlers have left many of the New England hills almost as bleak and bare as if nature had never been at the pains to cover them with soil and forest.

Influence of Vegetation on Rock Disintegration.

Vegetation, when once established, aids materially in the formation of a soil. It not only does so by holding in place the particles of soil already formed, so that they shall not be carried away by rain and wind, but it tends to collect and retain moisture occasionally, and thus enables water and carbonic acid in the water to act upon the rock, as will be explained directly. Moreover, the substance of the dead plants serves to increase the bulk of the soil, and to hold water upon the rock.

Plants contain withal various substances competent to corrode rocks, which must necessarily be brought into contact with the rock after the death of the plants, and which may also reach the rock while the plant is living through the diffusion and osmose of liquids from its roots.

Mechanical Disintegration by Roots.

Several plants are conspicuous from the power their roots possess of mechanically splitting rocks. Livingstone has dwelt on this

fact in the following terms: "In passing along near Rapesh [in South-central Africa] we see everywhere the power of vegetation in breaking up the outer crust of tufa. A moponé tree (Bauhinia) growing in a small chink, as it increases in size rends and lifts up large fragments of the rock all around it, subjecting them to the disintegrating influence of the atmosphere."

So too, it is said that in Sicily the lava beds of Ætna are sometimes purposely planted with the prickly-pear; and although it seems probable that, in the ordinary course of events, several centuries might pass before even the surface of the hard lava could disintegrate into soil, the roots of the cactus soon crack it, and in a few years break it up to a sufficient depth to allow of vineyards being planted. On the great pyramids of old Mexico, likewise, the same cactus has broken the porous amygdaloid rock with which the pyramids were faced, and has cut up the surface to a lamentable extent. But the vegetation which now covers these pyramids does good, in that it tends to protect their sides from the washing action of rains.

The action of roots as here described is akin to a mode of cultivation practised by Trappist monks in the elevated part of the Roman Campagna. They bore into the hard volcanic subsoil, blast it with dynamite, and find that seedling Eucalyptus trees planted in the mixture of shattered rock and earth succeed extremely well.

Chemical Disintegration by Roots and other Vegetable Matter.

The chemical action of roots, or rather of matters exuded from the roots, is undoubtedly of vast importance, both for the corrosion of rocks and as a means of enabling plants to take in food from the soil, as will be explained more in detail under the head of Manures. It will be enough to say here, that the juices of living plants often contain acid salts of one kind or another, and that it is known that some of these acid substances have power to dissolve and bring into the plant various useful matters that were previously lying outside the roots insoluble in water.

Several observers have called attention to the softened condition of the surface of rocks at spots where lichens are growing, as contrasted with the bare portions of the same rock. It is noticed that beneath the lichens a small quantity of the rock can often be cut or scraped away without much difficulty, while the adjacent uncovered surface is so hard that the knife makes no impression

upon it. Some lichens have been found to contain as much as half their weight of oxalate of lime, and oxalate of lime is a substance that would slowly corrode many rocks. Beside all this, the acid and ammoniacal products which result from the decomposition, i. e. the fermentation and decay, of the dead plants, are all efficient agents for the disintegration of rocks.

It has been noticed by geologists, that sands originally very strongly colored with oxide of iron sometimes become as white as if they had been soaked in an acid at points where they happen to be in contact with dead roots. The action of a root an eighth of an inch in thickness may extend to a distance of one or two inches. The same thing is often seen in woods and gardens, where sand has lain beneath rotting leaves. The sand is decolorized.

So too under moor earth in some situations. Not far northward from Boston, on the tops of the higher hills of New Hampshire, and on the coast of Maine also, a cold, sour black earth will often be noticed at the surface of the ground, immediately beneath which is sometimes a layer of remarkably white earth. The whiteness is due to the solvent action of acids that soak out from the black humus, and which leach out from the underlying clay and sand, the oxides of iron that formerly colored them leaving only the insoluble pure clay or sand.

It is to be remembered always that the "weathering" of rocks and of soils also goes on incessantly everywhere through all time. It is less conspicuous, it is true, in temperate climates, than in those which are warmer, but the effects of it may nevertheless be seen even in the most rigorous climates.

Agents that convert Rock to Soil.

The prime agents for the conversion of rock to soil are the corrosive action of air and water; the chemical action of matters dissolved by water; the growth of plants, particularly of those hardy mosses and lichens which find nourishment in the rock itself; and especially, in all cold climates at least, the disruptive force of ice.

Attrition by Wind and Water.

The attrition of particles of gravel and sand, moved by ice, or water, or wind, is another powerful means of disintegration. Witness, for example, the eroded trap dikes at Nahant and Cohasset and Newport, the drift scratches and planed surfaces upon the puddingstone of the vicinity of Boston, and the grinding up of the stones upon any shingle beach where surf is breaking.

Many sand-bearing rivers remove vast quantities of disintegrated rock, and grind it continually until it has become fine enough to form soil. Livingstone noticed long ago, that, in most rivers where much wearing is going on, a person diving to the bottom may hear thousands of stones knocking against each other. He adds, that this attrition being carried on for hundreds of miles in different rivers must have an effect greater than if all the pestles and mortars and mills of the world were grinding and wearing away the rocks.

Even the force of the wind is by no means despicable in this regard. Before the governmental planting of beach grass at Provincetown, on Cape Cod, the window panes in the houses of the fishermen there were quickly converted to the state of ground glass, and finally the glass was bored through and through, actually honeycombed, by the drifting sand.

Disruptive Force of Ice.

Of all the sources of action above mentioned, that of freezing water is the most conspicuous in Northern countries. A stone absorbs moisture; this moisture freezes, and since water in freezing expands to the extent of $\frac{1}{12}$ its bulk, the stone is either split into fragments, or shaken and made "crazy," or particles of dust or sand are scaled off from it.

It is through this agency that enormous heaps of broken rocks have accumulated at the bottoms of cliffs and mountains in every country where the winters are cold. But this frost action occurs as well with the smallest pebbles, and in every kind of soil. When marl is strewn in England as a fertilizer, the water that freezes within it is said often to cause the fragments of marl to crumble and fall to powder in a highly satisfactory way. So too upon ploughed land, it may often be noticed when the earth thaws in the spring that the coarser lumps and clods fall apart when the cementing ice within them has melted, because that ice in forming forced the particles of the clods asunder, displaced these particles from their original positions, and destroyed their connection one with another.

The disruptive force of ice has sometimes been applied methodically for splitting rocks in quarries, water being poured into holes and seams in the rock and confined there, and then allowed to freeze. Methodical experiments also have been made in this way with bombshells, and with thick globes of brass having small cavities at their centres, the brass being burst by pouring water into the cavities and freezing it. An instance is recorded where an amount of force esti-

mated at 27,720 lb. was exerted in bursting a globe whose cavity was no more than an inch in diameter.

A familiar example of the expansive force of ice is seen in the so-called "heaving" of the soil in winter, whereby walls are often overthrown, and crops, as well as the posts of gates and fences, lifted from their proper positions. As the common term is, the posts are "thrown out." In many districts in Northern countries, farmers are annoyed by the continual rising of loose stones to the surface of ploughed land, year after year, no matter how often they may be picked off. It is plain in this instance that the stones are lifted up together with the earth when it freezes, and that, whenever the earth thaws, more or less of the muddy loam falls or runs in under the stone before it can settle back to its old position. In this way earth enough is deposited beneath the stone to hold it up, and by the frequent repetition of these processes the pebble is finally thrown out upon the surface of the land.

Disposal of River Sand and Silt.

With regard to the mud or other finely divided matter which results from the grinding together of stones by the action of rapid rivers, or of surf, or of glaciers, as well as that washed out as such by rain from the soil proper, or cut out from the land by brooks, or rivers, or surf, it is to be noted that much of it has been deposited in past ages as alluvial land, particularly at the edges of brooks and rivers, to form the fringes of low-lying fertile soil that are known as intervales in New England and river bottoms at the West.

Fine mud is continually being deposited to-day at the mouths of rivers the moment they reach the sea; for by the action of the saline matters in sea-water the mud is made ready to settle, as will be explained more fully under the head of Sodium Compounds. Mud proper tends to subside in moderately shallow water at the mouths of rivers and in quiet bays, and in general in places that are not exposed to the action of breaking waves or sweeping currents. During the process of settling, there is naturally enough a strong tendency towards the sifting out, as it were, from the water-borne materials of those which are of similar kinds, i. e. of similar weights and shapes, with the result that each of them is usually deposited by itself in a special layer or bed. Thus it happens that some beaches are covered with pebbles and others with coarse sand, while fine micaceous sands are seen to accumulate by themselves in special coves or pockets.

Clay accumulates in great mud flats, such as are left bare by the lowest tides; while in many cases much of the finest mud and silt is caught and held entangled by marine or marsh plants, new generations of which subsequently grow upon it, so that in many situations dry land finally results. When such marsh lands are embanked and drained, as in Holland, highly fertile soils are obtained. So too, by slow geological processes of upheaval, mud flats may become marshes, and marshes may become dry land. In many swamps and ponds, also, mud accumulates slowly to fill them, and the process is often hastened by the growth of mosses and other water plants which hold the mud and grow upon it.

Disintegrating Action of Water.

The decomposing action of water upon rocks is very great, even if the water be regarded as perfectly pure, and no heed be taken of the chemical action exerted by carbonic acid and the various saline substances with which water that has been in contact with the earth is always charged. It is easy to satisfy one's self of this truth by an experiment suggested by the brothers Rogers. If a fragment of almost any kind of rock be ground to very fine powder, and the powder be moistened with pure water, it will be found after a while, on pressing red litmus paper against the moist powder, that it exhibits a distinct alkaline reaction. A portion of the silicate of potash, of soda, or of lime, contained in the minerals of which the rock was composed, is actually dissolved by the water.

By digesting powdered feldspar, hornblende, and various other minerals, with water for a week, the Messrs. Rogers found that from a third of one per cent to one per cent of the mineral was dissolved out by the water. If, for the sake of the argument, the lowest of these estimates be taken, — namely, that one third of a pound of mineral is dissolved out of every 100 lb. of the rock, — and this quantity be multiplied into the 3,500,000 lb. of material which go to make up an acre of ordinary soil, taken to the depth of one foot, it will be found that 10,000 lb. and more might be dissolved upon an acre of land. But it is known from the analyses of Voelcker that 15 tons of good half-rotted stable manure will supply to an acre of land no more than about 150 lb. of potash and 140 lb. of phosphoric acid; whence it appears that the solvent action of water upon fertilizing matters proper to the soil must be a power of real importance for the support of plants.

Significance of Pulverization.

The solvent action of water is of course exerted upon the solid rock, as well as upon that which is powdered. The only use in powdering the mineral is to enable the experimenter to present an enormous surface of it to be acted upon by a small quantity of water.

There is an instructive experiment of the French chemist Pelouze, which bears upon this point. After he had kept water constantly boiling for five days in a bottle of about 500 cc. capacity, he found that the dry phial had scarcely lost 0.1 grm., say a grain and a half, in weight. He then cut off the neck of the phial, ground this neck to powder, and boiled the powder with water in the body of the phial during another term of five days. But in this case the decomposition and solution was so great that fully one third the weight of the phial was lost, i. e. dissolved by the water.

So great is the influence of comminution that a glass vessel in which water might be kept for years without any very great loss of weight will give up as much as 2 or 3% of its weight if it be ground to powder and left even for a few minutes in contact with cold water.

The French geologist Daubrée put fragments of feldspar in cylinders of stoneware and of iron together with water, and made the cylinders revolve by machinery at such a rate that the fragments should be moved something like a mile and a half in an hour; i. e. they were made to travel about as rapidly as they might have done in a brawling brook. In stoneware cylinders enough silicate of potash was dissolved from the feldspar to make the water alkaline, while much mud was formed from the rubbing down of the mineral; while in the iron cylinders the water was made alkaline by the presence of potash itself, since the silica dissolved at first from the feldspar combined with oxide of iron from the cylinder.

On agitating 6½ lb. of feldspar with 5⅓ quarts of water 192 hours in an iron cylinder, i. e. long enough for the fragments to have been moved some 280 odd miles, nearly 6 lb. of mud were formed, while the water contained 193 grains of potash, or nearly 40 grains to the quart. The dissolved potash amounted to 2 or 3% of the potash contained in the original feldspar, but to no more than from 3 to 5 thousandths of the mud that was formed by the friction. The amount of dissolved potash was proportional to the amount of mud. In case the feldspar was "crazed" by being thrown into cold water

while it was hot, and then subjected to the friction, much more dissolved potash and much more mud also were obtained in a given time.

Solvent Action of Carbonic Acid.

The solvent power of the waters found in nature, even that of rain-water, is usually larger than that of the chemically pure water employed in the experiments above mentioned.

Carbonic acid, for example, is a powerful solvent of many minerals which are wellnigh insoluble in mere water, and this carbonic acid is almost always found in natural waters, usually to the extent of something less than one per cent. Very often it occurs in much larger proportion in water that has passed through soils containing limestone and vegetable matter. Hence carbonic acid plays a very important part in the formation and alteration of soils, not only by acting upon rocks directly, but by bringing other chemical agents to act upon them.

In the same way carbonic acid is of great importance for the growth of plants, since it enables water to dissolve and convey to the plants many fertilizing substances which are hardly at all soluble in pure water.

The air in the pores of cultivated soils is highly charged with carbonic acid, as has been shown by the investigations of Boussingault and Lewy, and of many other observers, and the formation of it is no doubt promoted by all those operations of tillage which tend to lighten the soil or to introduce air into it.

The waters of springs and rivers are far from being pure. They are in reality exceedingly dilute solutions of saline substances, such as the chlorides, the sulphates, and the nitrates of soda, lime, and magnesia, and they are consequently better fitted than mere water to promote the decomposition of rocks and the formation of soils. Phosphate of lime, for example, that is to say bone-earth, though scarcely at all soluble in pure water, is taken up in considerable quantity by water which contains carbonic acid, or even a salt of ammonia or soda. Pierre has shown that even the phosphate of iron, which is known to form in the soil from the action of iron salts upon solutions of the lime phosphate, is by no means absolutely insoluble in water charged with carbonic acid.

The beneficial effects resulting from the application of lime to stiff clayey soils have been attributed by some observers to the solvent, or rather to the decomposing, action of the lime upon frag-

ments of feldspar in the clay. In this case water and carbonic acid are the vehicles which bring the lime to the feldspar.

Rocks not Homogeneous.

One fact to be noted is that most rocks are composed of mixtures of several different minerals, some of which are much more readily acted upon by the solvents and other agents that work foı corrosion than the others are. Hence it happens that great masses of rock may become crumbly and honeycombed, or even fall down to the condition of gravel, though only a comparatively small portion of them has really been acted upon directly. By the action of oxygen for example, upon the protoxides and sulphides of iron and manganese, which are wholly absent from very few rocks, the integrity of the rock is impaired and the crumbling process hastened.

Aeration of the Soil favors Nitrification.

The action of oxygen in producing carbonic acid from organic matter in the soil has already been alluded to. There remains to be noticed, however, the agency of air in the production of nitrates, the so-called process of nitrification, which is one of the most important subjects in the chemistry of agriculture.

Until a comparatively recent period almost the whole of the saltpetre (nitrate of potash) used in Europe was produced in that country by artificial means. A mixture of loam, manure, marl, and leached ashes was thrown into shallow heaps or beds, which were sometimes even kept loose and open by means of racks and gratings. These heaps were moistened occasionally with barnyard liquor or with urine, and they were shovelled over at frequent intervals, pains being taken that air should be freely admitted to the interior of the heap. After some months of exposure to the air in this way the earth was leached methodically with water, and there was obtained a quantity of nitrate of potash and nitrate of lime.

Now, precisely as the process of nitrification went on in these artificial heaps, so must it also go on in every cultivated field to a certain extent; and it is well to insist upon this obsolete process of saltpetre making for the sake of impressing the lesson that one prime object of tillage, and of draining also, is the admission of air to the soil.

Every well-tilled field, or better yet, every well-tilled field provided with tile drains, is in some sort a saltpetre yard. In such a field, much of the manure and of the remains of plants, and of the humus in the soil, will readily be converted into saltpetre; and all

experience teaches the great value of this substance considered as a manure. Indeed, when the soil is merely stirred as with the hoe, or harrow, or cultivator, it must often happen that the formation of nitrates is promoted, and some part of the significance of the summer tillage of crops may fairly be attributed to an actual increase of fertility through changes brought about by the action of oxygen on organic matters in the soil.

But even if saltpetre be left out of consideration, it will still be true that the good effects produced by frequent ploughing, harrowing, and hoeing, and by draining also, result not merely from an alteration in the mechanical condition of the soil, but largely from the admission of air and moisture, which not only go to feed the plants directly, but so act upon various substances in the soil as to fit them to be taken up by plants. It is not sufficient, in order to the best results, to bury a seed and throw upon it some manure. Care must be taken that the soil around the seed, and about the manure also, is in such condition that air and moisture may come in to act their parts in the elaboration and conveyance of food from the soil to the plant.

In speaking of manure in this way, it must naturally be conceived of as if it were a part of the soil. It is in fact wellnigh impossible to draw any clear line of demarcation between fertilizers added to the soil and those derived from it. The idea of Tull would be realized if a soil could but be brought to such a degree of fertility that the yearly disintegration and oxidation of its particles, as induced by tillage, should supply an amount of fertilizing material equal to that needed by the annual crop. It was precisely this result which Mr. Smith attained.

CHAPTER VI.

IMPLEMENTS AND OPERATIONS OF TILLAGE.

It would be quite out of place in this book to describe in any detail the manifold implements which are used, or which have been used, for purposes of tillage. But it is noteworthy that, when considered from the chemical point of view, the dissimilarity of the

tools used for tillage is much less conspicuous than the fundamental points of resemblance which stamp them all as members of a single family. The wild Indian squaw used a pointed stick hardened by fire. It served her as plough and spade, as rake and hoe. More civilized nations, like the Hindoos, learned in the course of time to set their stick plough-wise, and to drag it through the soil by means of ox or horse power, and the later nations, Americans included, have labored in many ways to perfect this simple implement.

But while the stick grew into a plough, or a spade, or a hoe, on the one side, it grew into a rake or a harrow upon the other. And among and between these various implements there may be found all shades and degrees of differences and connecting links; witness the cultivator as one, the so-called "horse-hoe" of the earlier English writers.

Trenching.

Perhaps the most thorough-going tillage of any is the so-called process of trenching. In one sense this is really pretty much the same thing as digging with a spade, in spite of the fact that in trenching the earth is loosened and admixed to a depth of several feet; for in either case every spadeful of earth that is lifted is turned upside down at the same time that it is broken and loosened, not to say pulverized, and more or less admixed.

The main difference is, that in trenching the surface soil is methodically buried, while the subsoil is brought to the surface. To this end a ditch or trench three or four feet wide and two or three feet deep is excavated across one end of the field that is to be operated upon, and the earth from this first trench is thrown out upon the land. The first trench is then filled by throwing into it the earth that is dug out from a second trench, and the second trench is filled in its turn on digging out the third, and so on until the entire field has been dug over.

The chief peculiarity of the process consists in the fact that the surface soil from the second and from each successive trench is thrown into the bottom of the trench that preceded it. Upon this first or bottom layer is thrown the earth that was originally next beneath the surface soil, and so the soil is inverted, layer by layer, in such manner that the gravel or other subsoil that has been dug from the bottom of each of the trenches is finally left at the surface of the land.

Practically, the different layers of earth are much more thoroughly mixed than might be thought from the foregoing statement, for care is taken so to throw the earth from each new trench that the face of the heap of moved soil shall always slope towards the operator. Hence it happens that each spadeful of earth tends to run down the slant, instead of being left where it fell to form a horizontal layer. It is enjoined, moreover, in order to promote admixture, that pains should be taken to keep open a clear space two or three feet wide between the unbroken land and the heap of loosened soil, so that the workman can readily pick down the earth from the face of the solid side and let it fall to the bottom of the open trench before he throws it upon the slope of the soil that has already been moved. Thus it happens that each of the trenches is filled with soil that has really been pretty thoroughly mixed, as well as loosened; although, as a general fact, what was before at the top of the land is now deeply buried at the bottom of the loosened earth.

Different Modes of Ploughing.

Looking at the plough alone, which is perhaps the most variable of all agricultural implements, it will be perceived that after all not many different kinds of results are obtained by means of it. It is easy, however, to distinguish four kinds of effects which are sought to be produced in different instances. The first is the throwing up of the soil in high, narrow ridges, so as to expose the largest possible amount of rough surface to the action of frost and air. In this operation all the lower fertile portion of the soil is thrown up, together perhaps with a very little of the subsoil, in case the farmer wishes to gradually deepen his land.

Earth exposed in this way to severe cold and to alternate freezings and thawings during the winter and early spring will undergo no small amount of disintegration in the mere mechanical sense. But beside disintegration, thorough oxidation of the components of the soil will be insured.

Oxidation and Reduction in Soils.

As has been already insisted, roots need to be supplied with oxygen, and one important purpose of tillage is to make the earth friable and porous, so that air may freely enter it. But besides its influence upon roots, the action of air upon the soil itself needs to be considered. It constantly happens, in situations where there is no proper drainage, that land becomes not only soggy, but "sour,"

because the oxygen of the air cannot gain proper access to it; and even in the best of soils the lower layers are often very inadequately aerated. In the absence of oxygen, reducing actions set in between the various constituents of the soil, ferrous compounds and even black sulphide of iron and sulphuretted hydrogen are formed, as well as sour humus, so that the land often becomes improper for the growth of useful plants, and can support nothing but bulrushes, sedges, mosses, or other swamp vegetation.

In some boggy places the reducing and oxidizing actions may alternate in such wise that ferrous sulphate (copperas) is produced, which is a compound actually poisonous to plants. But by draining and ploughing such soils, or even by ploughing alone when the conditions are not too bad, air is brought into contact with the noxious constituents, and they are destroyed, either by mere oxidation, or by the action of certain microscopic organisms which prosper in presence of air. Wherever drains have been established, it happens that, as fast as the water with which the pores of the soil were clogged soaks away, air enters the pores to take the place of the water, and speedily brings about an entirely new set of chemical reactions. The soil now becomes a fit residence for quite another class of microdemes from those which infested it before.

Hoppe-Seyler suggests that some idea of these matters may be got by putting a quantity of mud from a barn-yard ditch or house drain into an open glass vessel, together with enough water to cover it, and noting how a brown film forms after a while at the surface of the black mud through oxidation of sulphide of iron to ferric oxide. Numberless microscopic organisms can be detected in the brown film, as well as compounds of nitrous acid. But neither nitrites nor nitrates can exist in the lower black non-aerated mud, and in case a little nitrite or nitrate of lime or soda should be placed in the lower mud it would immediately be reduced to carbonate of ammonia. On removing the layer of water from above the mud, i. e. by diminishing the height of the ground-water, the depth of the brown surface layer will increase, and a much larger part of the mud become inhabitable by the microdemes which prosper in presence of air.

Subsoils not fully Aerated.

Of course the amount of air in the pores of any soil will fluctuate, both with the varying barometric pressure and according as more or less liquid water comes in to occupy the pores, either from rain

or any other source. It may be said of all soils, that ploughing, like draining, checks the tendency towards reducing chemical actions within them, and thus in many instances prevents good land from falling out of condition. As a rule, yellow subsoils are yellow because of the presence in them of ferrous silicate, which will speedily change to red ferric silicate when brought to the surface of the ground and put into full contact with the air.

On the other hand, many surface soils are seen to be red from the presence of this same constituent, especially when they are worked continuously for many years, or until much of the dark humus has been used up and the color of the ferric compound can no longer be wholly concealed by it.

Any good surface soil which has been for months exposed to sun and air becomes more or less highly charged with products of oxidation, such as the ferric silicate just now mentioned, and when turned under by the ploughshare it carries these compounds into a lower layer of the soil, where they slowly give up some part of their oxygen while they are themselves reduced to a lower stage of oxidation. In this way compounds of the oxides of iron, in particular, act as carriers of oxygen, and they modify not a little the organic matters with which they come into contact. It thus appears, that by the act of ploughing oxidation is brought about, both in the soil which is freshly turned up, and in the lower layers also by means of the soil which is turned under, so that a very general freshening of the soil results.

Experiments on aerating Land.

The advantage of thoroughly aerating the soil is illustrated by the following experiment of Stoeckhardt. A level field of sandy loam rich in humus, overlying stony gravel at a depth of 20 inches, was divided into three plots, each one square rod in area. In one plot (No. I.) rows of drain tiles (1 inch in diameter) were laid 1½ feet apart. No collars were used to join the tiles, but they were laid loosely, with a straw's breadth of open space between their ends and a shard above this open space to keep out the earth. The drains were laid sloping, in such manner that, while their lower ends were 20 inches below the surface, their upper ends were only buried 10 inches deep. The upper ends of the drains were carried out to the open air by means of knee-shaped zinc pipes, and their lower ends were carried into open pits, so that air could at all times freely circulate through the pipes. At no time

during the experiment did rain-water enough fall to cause the drains to flow.

The drained plot No. I. was spaded 20″ deep. Neither plot No. II. or No. III. was drained, but one of them was spaded 10″ deep, and the other 20″. No fertilizer was put upon either of the plots. On May 17th, barley was sown. It came up well upon all the plots, but the plants on the aerated land immediately took the lead. They were noticeably more luxuriant, taller, and deeper-colored than the others. It seemed as if plot No. I. had been manured and the others not. At the time of blossoming a long drought set in, which greatly distressed the plants on the undrained land, and caused them to become yellow and sickly. The plants of plot I. retained their green color through the drought, though they were finally badly lodged by a heavy shower. All the plants were gathered on August 12th, and the yield per Morgen (= 0.631 acre) was as follows: —

	Lbs. Grain.	Total Crop.
Plot No. I. Aerated and spaded 20″ . . .	672	2772
" II. Spaded 10″	504	2072
" III. Spaded 20″	476	1964

On investigation, it appeared that the soil of the drained plot was really better supplied with water than the soil of the other plots, as will be seen from the following table, which gives the per cent of water in the soil.

	On July 8.		On July 22.	
	4″ deep.	8″ deep.	4″ deep.	8″ deep.
I. Drained and spaded 20″ . .	11.95	11.94	9.85	12.10
II. Spaded 10″ deep	5.87	6.07	6.15	6.20
III. Spaded 20″ deep	4.95	6.05	5.90	5.40

It was shown furthermore, by thermometric observations, that during the hot months July and August the soil of the aerated plot was constantly somewhat cooler than that of the other plots.

Ploughing to bury Sods.

As a second method of ploughing may be cited the mere turning over and burying of sods, in such manner that the old grass and roots may decay in a position favorable for the nourishment of the next crop. This sod-turning is a favorite device in New England.

Ploughing for Tilth.

A third method of ploughing consists in turning over, loosening, mixing, stirring, and pulverizing the soil, as by a spade or hoe.

This result is effected not only by the so-called trench-ploughs,

designed to break up and mix intimately the under soil and surface soil to the depth of 2 or 3 feet, but is produced in the majority of instances where an old tilled field is ploughed immediately before the introduction of a crop.

Where the soil is rich and mellow, a field ploughed in this way will differ but little from a garden dug over with a spade. By this kind of ploughing a part of the soil previously in contact with the air will be turned under, to freshen the lower soil, while there is brought towards the surface new portions of soil which from having been deeply buried have had perhaps comparatively little share in nourishing the preceding crop.

An effect similar in kind, though less in degree, is produced by the so-called moulding-ploughs, used for throwing up earth against plants grown in rows. It is produced in some part by cultivators and harrows; also when manure is ploughed under, or the land is ploughed across former furrows, or merely stirred to receive seeds.

Subsoil Ploughing.

A fourth method of ploughing consists in stirring the subsoil, the object being in this case merely to loosen the subsoil so as to permit the passage through it of air and moisture, without bringing any of the barren earth to the surface.

The significance of subsoil ploughing has already been hinted at when speaking of the capillary water of the soil. It is a method of tillage the merit of which cannot be too strongly insisted upon when applied understandingly in fit situations. The result of subsoiling is much as if, in the operation of trenching, when the ground has been dug out to the utmost depth meant to be reached, the workmen should loosen the entire sole of the trench by means of pickaxes and spading forks, and then shovel the soil from the next trench upon this loosened sole.

It is an important point to have the texture of the soil homogeneous, or so to say continuous, in so far as may be practicable. For example, in the case of a soil of good capillary power lying on top of a coarse loose subsoil, it might happen that the capillary connection between the two layers would be so poor and insufficient that the surface soil would be less thoroughly drained in wet weather than if the subsoil were as fine, and of the same texture, as the soil above it; while in dry weather the surface soil would suffer from drought for a precisely similar reason. That is to say, during and after rains, water falling upon such land might be held too long

near its surface because of inadequate capillary suction to drag it downward; and whenever continuous dry weather should set in to evaporate off the water from the surface soil, new supplies could not come up from below quickly enough to supply the waste. For this particular case trenching would doubtless work a more certain cure than subsoiling, because it is better fitted to establish uniformity of tilth.

Tillage increases the Capacity of Soils to store Rain-water.

One of the most important results of trenching anyway, and of trench-ploughing, is to improve the storage capacity of the soil as regards water. Into the loosened earth of the trenches rain-water will soak readily all the way, instead of running off from the surface of the soil, or soaking out sideways from the upper layers, as it would if the earth were compact and hard. But from this store of moisture in the trenched earth, from this wet sponge as it were, plants can easily supply themselves, and the surface soil can readily pump up its supply of moisture by means of capillary action.

It is manifest withal, that in soils which have not been trenched, but only subsoiled, there may be obtained an approximation to the moist sponge which is so great a desideratum.

Water-holding Power of Loose and Compact Loam contrasted.

Hellriegel divided a quantity of garden loam into two parts of equal weight, and compressed one part firmly while the other part was left loose. On determining the water-holding power of each, it appeared that the loose earth could retain 42% of its weight of water, while the compacted earth could only hold about 26%. That is to say, the water-holding power of the loose earth was almost one third larger than that of the compact earth.

Mr. Wilson, near Edinburgh, operating on land that had been tile-drained, ploughed a field 8 inches deep and subsoiled a part of it to a depth of 18 inches. The differences in the crops grown the first year after these operations are given in the table.

	Turnips.		Barley. Grain.	Barley. Straw.	Potatoes.	
	Tons.	cwt.	Bushels.	cwt.	Tons.	cwt.
Ploughed to 8 inches	20	7	60	28	6	14¼
Subsoiled to 18 "	26	17	70	36½	7	9½
Differences	6	10	10	8½	..	15¼

Mr. Maclean, in the same vicinity, made a similar experiment with the following result.

	Turnips.		Barley.	
			Grain.	Straw.
	Tons.	cwt.	Bushels.	Stone.
Ploughed 8 inches deep	19	15	54	168½
Subsoiled 15 " "	23	17	62	206½
Differences	4	2	8	38

In another case, where accurate accounts of the produce were kept, the good effects of subsoiling were seen for five successive years after the operation.

In this country Sanborn ploughed two plots of land, each of $\frac{1}{10}$ acre, seven inches deep, and then subsoiled one of them to a depth of nine inches more, so that this plot was stirred to a depth of 16 inches in all. After drought had become severe, he drove gas-pipes into the earth so that samples of the soil could be taken up from both plots to a depth of 15 inches. In the earth from the subsoiled plot he found 10.1% of moisture, while in that from the other plot there was only 8⅓%. The subsoiled plot yielded corn at the rate of 70 bushels to the acre, and the other plot yielded only 49 bushels to the acre.

Contrast between a hard Road-bed and a Tilled Field.

In order to gain a clear conception of the significance of such tillage as relates to the formation and maintenance of a deep bed of soil to hold rain-water, one needs only to observe a hard, dusty, macadamized road in the spring after a few days of dry weather; and to contrast the surface of the road with that of any well-tilled garden that abuts upon the road, that is to say, which is at the same level with it. To judge from the dusty road, one might suppose there was a drought, and the drivers are in fact all wishing for rain to "lay the dust"; but from the agricultural point of view there may not be the least need of rain, for the tilled land is moist and fresh even to the surface, and the ground is full of moisture. The road-bed has been built hard and compact, on purpose to exclude water. Rain-water cannot soak into it from above, nor can ground-water be sucked up by it from below. It is a hard pan at the surface of the ground. But in the arable land all the conditions should be as different from these of the turnpike as they can well be made.

The soil of the fields needs to be mellow, and not compact. If the earth is too stiff and its texture too close, seeds have great difficulty in germinating in it and many of them perish because not enough air can come to them, young plants have a hard struggle to

establish themselves, and even older plants cannot grow freely and vigorously. It is easy to show all this by the experiment of trying to grow plants in jars of pure clay. The plants languish and soon die, and their roots are found to be clogged with minute particles of the adhesive clay.

Generally speaking, the stiffer a soil is through the presence of clay, so much the larger will be its power of holding water, while, conversely, the more open the soil, the drier will it be. A soil that is too loose will give plants no proper chance to support themselves. The best soils will clearly be those which are neither too close nor too open, and it is the business of the farmer so to till and manure his fields that both these extremes may be avoided. When the tilth is good and deep, water will be held and supplied advantageously, and the roots of crops can penetrate as far and develop as freely as they will, without hindrance.

Risk that the Rain-water Store may be drained by Trees.

Another illustration of the advantage of having a bed of porous earth in the subsoil, which shall act as a moist sponge, is seen in a somewhat different way by the suffering of crops in times of drought in those parts of a field where the water is drawn out from the soil by special pumping engines such as trees or great weeds. It is said, that in some of the Western States, where wood is scarce, poplars, i. e. cottonwood trees, are sometimes grown on the arable land much as fruit trees are grown elsewhere. But when corn is planted in the same field with the trees, it is noticed that the crop grows well enough until a drought sets in, when the leaves of the plants near the trees soon wilt, and the plants fall behind those upon the other parts of the field.

The first thought naturally is, that the shade of the trees has hurt the corn; but a very little attention shows that the corn suffers most on the south side of the trees, where there is little or no shade. The fact is, that the trees pump up so much moisture out of the land that there is but little left for the corn. It is to be noticed in this case, that, if there were much moisture absorbed as vapor from the air, the corn near the trees would profit by it as much as the rest of the corn. In reality, it is subsoil moisture that the trees steal from the corn crop, and unless the rain-water bed can be made deep enough to supply both the corn and the trees, one or the other of these crops should be omitted.

It has been noticed in Algeria that the Eucalyptus tree may

absorb and evaporate twelve times the annual rainfall. Both in that country and in Italy extremely malarious places have been made healthy in four or five years' time by establishing plantations of this tree, which grows very rapidly and dries out the unhealthy locality.

In New England, quantities of gigantic sunflowers may often be seen growing around farmhouses. They have been planted for a double purpose, sanitary and economic; i. e. they serve to keep the soil dry outside the kitchen sink, and they supply a crop of seeds to be used as food for poultry.

Water transpired by Sunflowers and other Plants.

Experiments have been made by Sachs to measure the amount of water transpired by the leaves of sunflowers, as well as by those of other plants. It appears that, while much less water is evaporated from any given square inch or square foot of the leaf surface than would evaporate from the same surface of water during the given time and under like conditions of temperature, yet the leaves of a plant present such an enormous extent of surface to the air as compared with the surface of the soil in which the plant is standing, that plants have practically the effect of evaporating much more water from the soil they occupy than would be evaporated from that soil if it were bare of vegetation.

Sachs found that a sunflower plant which had been cut off close to the roots when it was 4 feet high and in blossom, and set in a jar of water, transpired 1.2 quarts of water in 118 hours; and since the plant had an amount of leaf surface equal to 763 square inches, the amount of water transpired by it was equivalent to a layer 0.09 inch thick spread over the entire leaf surface. But during these same 118 hours 0.21 inch of water evaporated from the surface of a body of water equal in extent to the leaf surface, as above stated.

As a matter of physiological interest, Sachs urges that the water is not really transpired from the mere superficies of the leaves, but from the walls of intercellular spaces, which in the sunflower represent a much larger surface than that of the outsides of the leaves, — perhaps ten times larger. But since the air within these spaces is wellnigh saturated with moisture, water can only transpire into them rather slowly. It appears, indeed, that the amount of water transpired from a given surface of these intercellular walls in the sunflower cannot amount to more than $\frac{1}{23}$ the quantity of water that evaporates from an equal surface of water.

Cooling Effect of Transpiration from Plants.

It is notorious that the enormous quantities of moisture exhaled by trees has a very considerable influence in cooling the air in the immediate vicinity of the leaves; for a great amount of heat must of course be used up, or made latent, wherever liquid water is changed to the gaseous form. The temperature of a place may in fact be perceptibly lowered by the evaporation of water from vegetation.

The freshness of a grove or forest does not depend alone upon the circumstance that the trees shade the ground, and so keep it cool, but that the evaporation of vast quantities of water into the air takes heat from that air. Methodical experiments have shown that in any given locality the air of forests during the growing season is both moister and cooler than the air of open fields. Even the soil and the trees in a forest are decidedly cooler in summer than the air of the open fields. Just so it is that greensward feels cool because of the transpiration of water by the blades of grass.

A noteworthy example of the influence of the exhalation of water upon the temperature of the air has been afforded by the cutting of the canal at Suez. The climate of the Isthmus has been sensibly modified by the opening of the canal, and the extension of cultivation along it, the summers being now decidedly cooler than they were before. This improvement in the temperature is attributed to the infiltration of water into the desert soil, and in part to evaporation therefrom, but largely to exhalation from the vegetation which has sprung up near the banks of the canal, and over a broad belt of reclaimed land that is irrigated by the fresh-water canal.

In so far as woodland is concerned, the shade and the litter of course lessen evaporation from the very surface of the ground, though the amount of water abstracted from the whole of the ground by the pumping action is enormously larger than could possibly be removed by mere evaporation from the ground itself by sun or wind.

Too loose a Subsoil objectionable.

Manifestly, if the subsoil were already too loose and open, trenching and subsoiling in it might do harm, by letting the rain-water run to waste more rapidly even than before. There may be danger too, in some special cases, in breaking through the sole, as it were, upon which the soil proper rests. It might even happen in some

cases, where the surface soil is fine, that it would run away mechanically with the rain-water into the depths of the earth if the sole were broken. Marshall has noticed such soils as these in some parts of England; but, as a general rule, even gravelly subsoils are tolerably compact.

Excepting coarse sands, which are wellnigh incorrigible, the natural tendency is for gravel, as well as clay and loam, to become compact and bound together. As time rolls on, the particles of gravel settle down one upon another into close contact. They are beaten together by rain, and the finer particles continually tend to fall or float into the interstices between the larger particles. Hence, excepting the case of coarse sand, as was said, where the particles are pretty much all of one size, there are comparatively few subsoils that would not be benefited by trenching, or subsoiling, or by any other method of loosening.

Rain compacts Surface Soils.

The influence of rain in impacting soils is well seen upon lanes and avenues that have been covered with sharp, non-binding gravel, i. e. in cases where no clay is present to cement the particles of gravel together. In the spring, after the frosts of winter have loosened the impaction which was brought about by the autumnal rains, the surface of such roadways is loose and incoherent; but the rains of spring soon beat the particles of gravel together, and make the surface of the road firm and hard.

This remark is as true of the soil of tilled fields as it is of the gravel of avenues. The frosts of winter and the tillage of spring loosen the surface soil, but the beating rains soon form a compact crust at the surface, which has to be broken up with hoes and cultivators.

It is to be noticed that, when particles of gravel are moist, they readily slip and slide upon one another, until they become firmly wedged in the chinks. It is because of this circumstance that avenues are rolled after rain, and that road-makers take care to sprinkle newly spread gravel with water before ramming or rolling it. Both the ramming and the rolling are mere extensions or exaggerations of the beating action of rain.

Hard Pan.

Beside the mere mechanical impaction of soil, it must be remembered that there is often a tendency towards the chemical binding of the particles of gravel and soil. As Professor Johnson has set

forth in "How Crops Feed," p. 332, there are chemical forces, opposed to disintegration, which tend continually to make rocks out of soils by binding the particles of the soil together.

Sandstones, conglomerates, slates, shales, and many other kinds of rocks, were once soils which have been cemented or solidified by chemical action and pressure. Similar changes occur continually, though they are commonly slow, and hardly noticeable while in progress. In the vicinity of Boston, partially disintegrated pebbles of dolerite or trap may often be seen incrusted with a newly formed layer of rock that has resulted from the oxidation of the disintegrated material, and perhaps from its combination with silicates from the soil. These crusts are strictly analogous to "hard pan," which is, properly speaking, a true rock, which has been formed beneath the surface soil by the cementation of the sand or gravel of the subsoil by means of humate of iron, or of silicate of iron, or of silicate of lime, or the like.

One of the chief difficulties foresters have had to contend with in planting the wild heaths and moorlands of Europe is to break through a thin, hard, impervious pan of rock, which commonly underlies the moor earth at no great depth. Nowadays they break through this pan at intervals, either by picking with pickaxes, or by running lines with a strong subsoil plough at distances of 8, 10, or 12 feet, so that rain-water may soak away from above, and that some capillary water can find its way up from below on occasion, and that the roots of the trees may go down the cracks. So, too, in the old "pricking" system of drainage, the idea was to break through a pan.

Capital illustrations of the formation of rock similar to one kind of hard pan may often be seen where fragments of metallic iron are left in contact with silicious sand under sea-water.[1] The oxide formed on the surface of the iron by the action of the salt water speedily unites with silica, not merely to cement the particles of sand, but to form an intimate chemical compound which completely incrusts the iron with a layer of hard smooth stone, and if perchance a corner of this incrusting stone be broken off, the iron beneath it will slowly rust away and be washed out as rust, leaving a hollow shell of the same shape as the original fragment of metal.

Reversion of Soils to Rock as important as Disintegration.

The tendency of soils and of constituents in the soil to revert to rocks, and indeed all the chemical changes which occur in soils, need

[1] As at Old Point Comfort in Virginia.

to be kept in view as constantly as those which relate to mere disintegration. Some idea of the state of things which must actually exist in soils may be got by considering the phenomena of pseudomorphism and petrifaction, which are familiar to mineralogists and geologists.

Pseudomorphs are minerals presenting definite crystalline forms which do not belong to the chemical substances of which these minerals now consist, but to other substances which have disappeared, either wholly or in good part, out of the crystals, and been replaced by the present materials. Pseudomorphs, consequently, are not really crystals, although they occur in crystalline shapes. They are merely aggregates of substances which have been deposited little by little, as fast as the contents of the original crystal have been removed. Petrifications and fossils in great variety have been formed in the same way. But precisely such alterations must continually occur in soils, and in the particles and pebbles that are contained in soils, as well as in the rocks from which soils are formed.

The Forms of Ploughs differ with Localities.

In ordinary ploughing, the kind of implement employed and of furrow turned must of course depend in great measure upon the soil one has to deal with. The drift gravel of New England manifestly calls for a very different instrument from that which has been used from time immemorial to stir the soft river mud of Eastern countries.

Some writers have held, in general terms, that a deep, stiff soil can never be ploughed too deep, and can hardly be ploughed too often, provided the land is not too wet nor too dry at the moment of ploughing. But with soils so thin and poor as most of those in New England, this dictum would be utterly untenable. Care and judgment must be exercised always to avoid waste of vegetable remains, and to avoid loss of water, as well as to leave the infertile subsoil where it belongs, and not to bring too much of it to the surface at any one time.

A distinction must always be made, too, between rough, stiff, and so to say crude land, that needs to be worked pretty thoroughly in order that it may be manured with profit, and land which is already in good tilth and good heart. In the case of the latter, too much ploughing might do harm, especially if the land had been recently manured, both by exposing the soil (and the manure) too freely to the air, and by tending to pulverize the earth too finely.

Practical men hold that, for land already fertile, any undue stirring, aeration, or pulverization is to be deprecated. As bearing upon this belief, it is to be noted that land left for some time untilled — a clover field, for example — often gains appreciably both as to its mechanical condition and its fertility. Old sod land also is not infrequently found to be in very fair condition.

The farmer will naturally strive to bring sandy and gravelly soils into such condition that they may ultimately be ploughed deep, and fitted to absorb and retain moisture, whenever it is possible to do so, economically speaking; but in order to do this by mere surface ploughing, long-continued attention to the kinds of crops taken and of manures employed will be as necessary as judicious tillage.

Application of the various Methods of Ploughing.

In case mere disintegration is sought for, the kind of furrow first alluded to, viz. the sharp, high ridge, would be appropriate. It is often drawn to that end in various localities. It has sometimes been urged that American farmers might often do well to imitate this European practice, and it may be true that this should be done in the case of soils naturally strong, that need to be thoroughly worked. But in New England there are comparatively speaking few soils where disintegration can be counted upon as a direct, speedy, and available resource.

The hard polished gravel which composes the substratum of so many New England soils is little prone to decomposition. Of course it does decompose slowly, and the plants which grow upon it seek out those portions of the decomposed matters which are fit food for them, and bring them to the surface. It is by this process of slow decomposition, and the accumulation of the decomposed matters by plants, rather than by any rapid and easily appreciable disintegration, that New England soils appear to have been formed for the most part. Herein apparently lies the justification of the very common practice of ploughing a shallow furrow so as merely to invert the sod.

The growing of corn, potatoes, oats, rye, and grass upon inverted sods seems in fact to be a sort of specialty of New England farming; and it does not appear probable that the results now obtained with these crops can be much improved upon by merely changing the style of ploughing, unless indeed the subsoil plough be used more frequently than it is now. But in the case of clay soils, and of deep soils, after the inverted sod has rotted, it may be true that our

farmers pay too little heed to the special requirements of such soils, and continue to plough them too much in their usual way.

A rough furrow laid up expressly to promote disintegration would seem to be appropriate occasionally upon many deep soils that have been long in tillage, and upon all soils which decompose readily, such as rotten gravels and clays, and in general upon all deep soils that rest directly upon their native rocks.

Many farmers, even in fertile regions, have urged that it is important occasionally to plough land deeply in autumn, for the sake of bringing up a quantity of the lower soil to improve the texture of the soil at the surface, as well as for the purpose of bringing the inert lower soil to the air. There can be no doubt that, in many situations, this argument must have much force, especially in cases where the surface soil is of such character that frequent tillage of it alone is apt to injure the tilth.

After the deep ploughing, some non-fastidious crop, such as oats or potatoes, would naturally be grown first upon the dead earth. One merit of potatoes would be, that in hoeing them the crude earth would be mixed with the old surface soil, and be the better prepared for bearing winter grain.

It should always be remembered, that the disintegrating and nitrifying action of air were the points specially sought for in the old system of letting land lie fallow for a season. The destruction of weeds during the fallow was a merely incidental gain. So far from the fallow land being left at rest, it was, in the old English practice, really ploughed and stirred frequently.

Derivation of the Word Manure.

Nothing illustrates better the high repute in which tillage has always been held among practical men than the fact that the original meaning of the word *manure* was *manœuvre*. That is to say, the man who worked his land manured his land. Fallow land meant originally red land, as in the term *fallow deer;* for much land that is thoroughly worked and exposed to the oxidizing action of the air will show red by contrast with ordinary land, because of the large proportion of ferric oxide that forms in or upon it.

Circumstances modify Tillage.

Of course the method of tilling a soil of any given kind will be influenced materially by the character of the subsoil, and the height of the ground-water, as well as by the climate of the country in which the soil is found.

The style of tillage will be different in different countries, according as the average heat and moisture of the localities are different. The requirements of Italy and of Scotland, for example, or of Old England and of New England, or of the Eastern States and of California, are manifestly dissimilar.

After all is said and done, the relation of the soil to water will still remain the most important consideration. No matter how rich a soil may be in itself, it can hardly be made productive if it happens to rest immediately upon an undrained, stiff clay, or if there be only a thin layer of it covering a deep bed of coarse dry gravel. But by draining in the case of the clay, or by gradually deepening the loam in the second case until it has become a foot or more deep, then crops may be grown in spite of the unfriendly subsoil.

Even in the climate of New England, a bed of underlying gravel is not wholly to be deprecated; for if the upper soil be only deep enough to absorb and hold moisture, the open subsoil below it has the merit of acting much in the same way that a series of tile drains would act. It is only when a thin soil reposes on a smooth ledge of rock that the case is really hopeless. In this event, irrigation is the sole resource.

In speaking of tillage, it is to be remembered that one of the most important effects of thorough drainage consists in preventing the occurrence of wide extremes of wetness or dryness, of heat or cold. A drained soil is not only drier in a wet season than one which is undrained, but it is moister in dry seasons, — is warmer in cold weather and cooler in hot weather. And the same remark would be true of a deep soil overlying sharp gravel.

But, as has been said, the upper soil must be tolerably deep in order to good results. So long as the rootlets of the plant have abundant room for growth, and plenty of space from which to collect the capillary moisture of the soil, they can withstand many vicissitudes; as when, for example, the loosened surface soil dries out to the depth of several inches under the influence of a protracted drought. But with only a thin layer of soil, such an experience as this would be fatal to the crop.

Soils are not crushed, but crumble, by Tillage.

It would be of interest, if space permitted, to discuss in some detail the practical question what methods of tillage are best suited to the various kinds of soils. Much might be said on this topic. In any event, there are two or three points of general significance

relating to it which need to be dwelt upon. It is noteworthy, for instance, how little there is, comparatively speaking, of any crushing action in most of the processes of tillage. The plough, for example, does not grind the soil to powder, but merely throws it up in such wise that it may fall into a looser condition than it was in before.

The ploughshare works to counteract the continual settling together and impaction of the earth which occur when a field is left to itself. When earth which is slightly moist is thrown up into little ridges, i. e. furrows, the mere act of drying makes the earth crumble and fall down to a loose, light, porous powder.

The merit of ploughing loams in spring, when the land is still rather moist, is not merely that the ploughshare slips easily through the soil without distressing the animals, but that the furrow as it dries falls down of itself to the condition of loose earth. Of course the soil must not be too wet at the time of ploughing. There is a proper and an improper degree of moisture, as practical men well know.

Clays are hard to till.

If the soil when ploughed is wet enough to be plastic, and particularly if it be a clayey soil, then the furrow will dry either to a hard mass, or to hard clods such as the harrow cannot break, and the ploughing will likely enough do more harm than good. It is for the purpose of breaking up these hard clods, which are so difficult to avoid in clay soils, that the toothed rollers called "clod-crushers" are used in Europe. Indeed, the trouble and cost of working clay lands is so great, that, in spite of the fact that they are generally by no means lacking in respect to fertility, there is said to be a noticeable tendency almost everywhere to keep them in grass; i. e. wherever there are other kinds of land available for cultivation and the farmer has a choice.

As with clay, so it is with almost any too finely divided soil. In pot experiments, where plants are made to grow in powdered rocks, it has been found essential that the rock must not be ground to a very fine powder; for when such fine powder is moistened, its particles cling together and form a compact mass, which is eminently unfavorable for the growth of plant roots. Moreover, when the mud thus formed by moistening finely powdered rock with water is allowed to dry, it forms hard lumps, that are wellnigh impenetrable by plant roots or by air. But in more coarsely pow-

dered rock, i. e. in powder whose particles are not fine enough to "cake," it is easy to grow plants by merely adding whatever elements of plant-food the rock may happen to lack, notably nitrogen. (Compare Dietrich, Hoffmann's Jahresbericht, 1863–64, p. 67.)

Processes of Kneading are to be avoided.

The practical difficulty of cultivating wet clay enforces a point of the utmost importance, and of great scientific interest; viz. the necessity of avoiding kneading and "puddling" in all operations of tillage. As is well known, when engineers wish to make a water-tight reservoir, they spread a quantity of clay upon the bottom, mix it with water, and "puddle" the mixture by long-continued harrowing, raking, and hoeing of it; that is to say, they knead it to and fro, much as in the mixing of lime and sand for mortar, but more thoroughly.

This puddling process has the effect both of removing particles of air from the clay, and of breaking down all granules or compound particles, so that there is finally nothing but an impalpable clay dust, which settles upon itself most compactly, and clings together as a whole with great tenacity, so that neither water nor anything else can pass through it.

In the kneading of clay by the potter's hands or feet, and in the process called "tamping," the same result is arrived at; that is to say, there is destruction of that friability and granulation of the particles of soil, which constitutes good tilth, while there is produced an increased plasticity of the material, and a capacity of forming masses of stony hardness when dry, i. e. clods.

Where the tillage of a soil is good, — that is to say, where the soil is ploughed and worked at just the right time, when it is neither too wet nor too dry, — the gentle stirring and loosening tend to undo the tamping and puddling which have been brought about by rain. By means of the wholesome tillage, the clay-dust just now spoken of is made to coalesce or "flocculate," as the term is, into granules or compound particles fit for plants to live and grow in.

Extremely Fine Soils resemble Clay.

The foregoing, though particularly true of clay, applies in some sort to all extremely fine soils, such as river silts and marsh silts, and to the very finest portions of all soils. It appears to apply in some degree to much of the prairie soil at the West. Knop mentions the case of a reclaimed bog that bore excellent crops for nearly

fifty years without any addition of manure, and then got into such condition that complaints were made that the peat dust killed the crops in times of drought. Analysis showed that the soil contained an abundance of plant food and no hurtful chemical substance. The trouble was, that the tilth of the humus had suffered, and that the soil now fell easily to too fine a powder.

The farmer must strive always to avoid kneading, and must seek to bring about crumbling. A loosely granulated or flocculated condition of the particles of the soil constitutes good tilth, while kneaded or puddled soils are unfit for the growth of plants.

Practice consists with Theory.

The reasons of some of the practical rules that have been laid down by agricultural writers in respect to the ploughing or working of heavy land become plain enough when viewed as devices for avoiding puddling. Thus in Morton's Cyclopædia of Agriculture it is said of English practice: "When barley or oats follow a bare fallow, the old practice was to lay on the manure in winter during frost, to spread it on the surface, and to allow it to lie there until the first good weather in spring, when it was ploughed under, and the seed was drilled in. But now many farmers endeavor to get the manure laid on in the autumn immediately after harvest, and to plough it in at once. The winter frost mellows the surface of the land, so that it will be found loose and friable in the spring, when the seed is easily drilled in, and a fine tilth obtained."

And again: "In summer-fallowing, on several of the varieties of English clays, the harrow and roller are used very sparingly. The land is never broken down to a fine mould, but is allowed to remain in a rough cloddy state. The reasons why this practice is persisted in are as follows: — If the land were worked fine, after a stirring furrow, the first heavy shower of rain would cause it to run to a solid mass (of mud), completely impervious to sun and wind, and if, while the land was in this state, drought should suddenly recur, no ploughshare could penetrate the soil."

There is a story current in New England of a farmer who, having been called to dinner when his onion bed was but half sown, got no good from that part of the bed which was seeded after he had finished his meal. The seed sown before dinner vegetated freely, while that sown after dinner never came up. The trouble was, that a slight fall of rain during the meal time had destroyed the tilth of the seed-bed.

It has been said of Scotland that on very heavy soils root crops are rarely attempted, because of the difficulty of obtaining a sufficiently fine tilth for the seed-bed, not to mention the risk of trouble in getting the crop off the land in case bad weather should set in early in the autumn.

The familiar observation, that land on which crops are growing often appears to be mellower and in better tilth than adjacent bare land, depends in part upon the fact that the surface of the bare land is liable to be frequently puddled and beaten together by showers, while the leaves of growing crops shield the soil beneath them from the direct action of rain, to a very considerable extent.

Freezing may help Puddling.

Although, as was said before, the freezing of a soil tends naturally to loosen it, and is really of the utmost importance in this respect, freezing may nevertheless help the puddling process unless care is taken to prevent such action.

Suppose, for example, that a well granulated soil, such as commends itself, freezes in winter weather, i. e. that the water within the granules congeals. By the act of expansion due to the freezing, each granule may be more or less completely torn to pieces, and be reduced to a number of separate particles of dust, held asunder by particles of ice. If such land were to be ploughed immediately after it had thawed, it would be an easy matter to puddle the particles of wet dust, which need only to be stirred in order that they may stick together. But if, on the contrary, the soil is left at rest after the thaw long enough for the dust particles to cohere into granules, as they will naturally do if left undisturbed, and if care be taken to plough only at that condition as to moisture which experience has shown to be fit for this particular soil, then the new-formed granules or flocks will be looser than ever.

Mending of Roads.

In the mending of roads and avenues, ready application may be made of the foregoing facts. I have myself observed repeatedly, on placing fresh, coarse, non-binding gravel in the ruts of a narrow lane during the first thawing days in the spring, and leaving the gravel to soak, and freeze and thaw during the next week of freezing and thawing weather, that a hard, compact road was formed at once; for the gravel was thoroughly tamped and puddled by the action of the frost, combined as it was with rolling and pressing by the wheels of passing vehicles. But in case the gravel was put upon

the road a day too late, it remained loose and incoherent during the entire season.

The rule is, then, to roll avenues as soon as the frost will permit, in order to make them hard, and, if fresh gravel is to be put upon a road, it should be spread before the last freezing weather of spring. But fields, on the other hand, should not be ploughed in the spring after frost, until time enough has been allowed for the soil dust to granulate. It is well known to farmers, that ploughing land, when it is too wet after a freeze, is worse than ploughing too soon when the land has been wet with rain, though the latter is bad enough.

An instance of puddled earth specially familiar to men bred in cities is seen in the street mud which is scraped off the pavement with hoes in the spring after the ice has thawed. On drying, this material forms a hard cake, which is most unfriendly to vegetation. During the winter this mud has frozen and thawed many times, and it has been stirred and rolled by hoofs and wheels. It is fine earth, which has been thoroughly puddled. Farmers near Boston formerly bought this stuff, and used it to mulch fruit trees, for which purpose it is well suited, as will be seen hereafter.

Attempts have also often been made in the city to employ this material, instead of loam, for filling in the front yards of dwelling-houses, which are to be sodded in due course. When applied in this way the dried mud often fails signally to serve any useful purpose, because of ignorance on the part of the people using it as to its peculiar qualities. Plants cannot thrive in puddled earth, i. e. they cannot grow in a thick layer of it, nor can water penetrate it. When employed to improve gravel, the true way of dealing with the street mud would be to use but little of it on any one spot, and to harrow or rake this little into the gravel methodically, layer by layer, instead of leaving a bed of it by itself at the surface of the land. When thoroughly commingled with gravel, the street mud would probably soon form a useful soil.

Other Examples of Puddled Earths.

Another substance easy to puddle is fine coal ashes. I have seen most admirable, hard, compact sidewalks made by spreading, one above the other, repeated thin layers of sifted coal ashes, and wetting, raking pertinaciously, and rolling each layer. This job requires patient toil, but the results of it are surprising.

Still another familiar example of puddled earth is seen in the layers of slime which are left whenever puddles of water upon the

highway dry up. Indeed, the particles of clay or fine earth, which so obstinately refuse to settle from a mud puddle, and which give the puddle its name, are not at all "flocculated" or "granulated," but dust-like. Such mud and slime as this are peculiarly obnoxious to plants. On being floated into the soil by rains, they clog its pores; and they clog the cells of plant roots also, whenever they happen to come into intimate contact with them. On trying to grow plants in pure pipe-clay admixed with sand, it will readily be seen how easily the roots are distressed by this clogging of their cells.

Some pond muds are, to all intents and purposes, puddled earth, and the diversity of action noticed when such muds are used as fertilizers doubtless depends in some part on differences in the mechanical condition of the different samples. Some of these muds must be excellently well suited for use upon sandy soils, though perhaps they might be distinctly hurtful to some loams. Discretion needs to be exercised in using such materials.

Earth-worms are Pernicious.

Gardeners are familiar with the fact that the presence of earth-worms in the soil of plant pots is highly detrimental to the health and growth of the plants. The trouble appears to be, that worm-casts consist of thoroughly puddled earth, i. e. of earth which has been completely deflocculated by passing through the bodies of the worms. Whenever water is poured upon the soil in the pots, the worm-casts pass into the condition of slimy mud, which soaks into the earth to clog its pores and those of the roots as well.

Amelioration of Clays.

From what has been said above, it appears that the trouble with strong clay soils depends, not merely on the difficulty of finding appropriate moments in which to till them without forming clods, but also upon the risk that the pores in the soil, and even the cells of the roots of the crops, may be clogged by the muddy liquors which are formed in such soils by rains.

By the use of long manure, marl, lime, calcareous sand, burnt clay, coal ashes, or even silicious sand or gravel, it is possible to correct in some measure both these faults of clayey soils, particularly when the clay is not too plastic and pure to begin with.

By means of steam ploughs, also, enormous improvements in cultivating clay soils have been made in England. With the steam plough the land can be broken up with a rapidity and thoroughness

which was impossible before, so that the farmer can now take full advantage of moments when such soils are dry and in proper condition to be worked.

Some Soils not to be tilled when Dry.

It is not alone when soils are wet that it is wrong to try to till them, for it is found that some fine soils, composed of minute particles of uniform fineness, such as certain river deposits, suffer very much on being ploughed when they are very dry. They are soils whose granules or flocks have so little coherence that, on drying, they fall to dust of their own weight, or on the least shock or movement to which the earth is subjected.

In ordinary soils, the beating of rain destroys the floccules at the surface merely, by a process of mechanical puddling, though it may be that the surface crust is somewhat deepened by the infiltration of clay-water to the layer of soil next below the surface; but in the fine silts now in question, the tamping process may go on to an appreciable depth, i. e. as far as the soil dries.

In general, the soils which permit the greatest freedom of tillage are those whose particles are not of uniform size, — good garden loams, for instance.

Very Fine Soils are apt to need Tile Drains.

It is said that many prairie soils which had sufficient natural drainage at first get into such a condition, after years of cultivation, that it becomes almost absolutely necessary to tile-drain them. It appears that the continued cultivation of such finely divided soil tends to dry-puddle it somewhat, — to such an extent, namely, that water finds no easy passage through it.

To show how antagonistic puddling is to draining, instances might be cited from experience in the Western States relating to the mud roads of the prairie country. It would be an enormous gain if these loam-built roads could be kept dry enough and hard enough to bear wagons in soft winter weather; and it was thought at one time that tile drains laid beneath the surface of the road would help to keep the earth dry. But on trying the experiment, the operators got no good for their trouble. The mud in winter and spring was just as deep on the tiled roads as upon the others.

A moment's reflection teaches that the soil at the surface of the road is so tamped and puddled, all through the year, by passing vehicles, that water cannot pass through it. It might almost be said that the puddled surface soil has no connection with the sub-

soil in which the tiles were laid. Of course, in wet weather some of the puddled earth is softened and stirred up to the condition of mud by passing vehicles. But water cannot flow through such mud, and in so far as the mud is ground into the soil below it, so is the depth of the puddled earth increased.

Risk of Puddling in Subsoil Ploughing.

In view of what is known about the puddling of soils, it is now easier than it was formerly to understand one very important point in respect to the use of the subsoil plough, viz. the risk there is of puddling a clayey subsoil when this instrument is used upon it at an improper season.

A soil may be in excellent condition for tilling at the surface, and yet be too wet below; so wet below that the action of a subsoil plough would be simply to knead and pack the earth to a firm tenacious dough, impervious to roots and to capillary moisture. In this event, subsoiling would do far more harm than good.

The question when best to subsoil is really a perplexing one; for with land of the supposed quality, it would not be easy to hit upon a time when the soil is fit to plough both at the surface and beneath. All is, the farmer must think about the matter, and must try to get as near the desired point as may be practicable.

It goes without saying, that late summer or early autumn would be the natural time to approach the subject, for in spring the moisture dries out from the land slowly. But the trouble is, that, if the subsoiling be done in autumn, the ground will subsequently settle somewhat, in the course of the winter, and there would thus be lost a considerable part of the effect which in the case of spring ploughing would have served to benefit a crop. Hence it has been urged, that it is best to wait long enough in the spring until the condition of the land is fit, and then, after subsoiling, to put in some late crop, such as fodder corn, millet, or any late soiling or ensilage crop, — perhaps even buckwheat.

It is probable that this tendency to puddle the land has done more than any other one thing to throw the subsoil plough into disrepute.

Summer or Surface Tillage.

Another point of prime importance is the question of surface tillage, — that is to say, summer tillage, — such as is performed with the hoe and the cultivator. The proper conduct of this surface loosening of the soil has an enormous influence upon the husbanding

of the store of capillary water in the lower soil; and it is from this store of moisture that most crops have to depend in dry summer weather.

For the sake of the argument, let it be supposed that a soil has been trenched, that the trenched earth has been charged by the spring rains with as much water as it can hold, and that dry weather has now set in. It is manifest that the more such a soil as this is ploughed or stirred, the more quickly will water evaporate out from it, particularly from the surfaces of the stirred portions; and it is plain that any soil made loose by stirring will expose a far larger surface to the atmosphere than a compact soil can.

Evaporation will naturally be proportionally rapid accordingly as the surface exposed to dry air is larger. But it is none the less true, upon the other hand, that the processes of surface stirring may hinder the waste of water from the layers of soil immediately below that which is actually disturbed; and it is a fact, that, by judiciously tilling the surface soil, the waste of water from the standing room of the crop may be lessened.

To return for a moment to the bed of trenched soil charged with moisture, let it be supposed that no tillage has been practised since the crop was planted, some time since. The surface soil will naturally have settled down upon itself, since it was disturbed for the planting, and there will be found a more or less perfect capillary connection between the surface and the underlying soil in which the water is stored. So long as this good capillary connection is maintained, much water will be rapidly drawn up to the surface, and will there be evaporated off into the air, without serving any useful purpose for the maintenance of the crop. But if the dry surface soil be scratched or stirred, and made loose and light, the capillary connection with the underlying soil will be impaired, and the power of the soil to bring up water to the very surface will be greatly lessened.

The real desideratum is to maintain the best possible capillary connection between the lower layers of soil, where the store of water is, and those layers in which the plant roots are growing. More than this is not wanted, and pains must consequently be taken to break up continually the capillary connection between the surface and the root bed. It is desirable that water shall rise freely into the root bed; but when it has got there, it had much better go out through the plants, and not by way of mere evaporation from the surface soil.

It is an important point, therefore, in good husbandry, in very many cases, that summer surface tillage should be shallow. If the soil were disturbed to too great a depth the roots of the crop might be forced to go down in search of water to depths below those where the best soil and the most manure are situated. Still, there is one thing to be said in favor of deep summer tillage; viz. that, by admitting air freely to the soil, it may specially favor nitrification. This fact should be borne in mind, and perhaps worked for in cases where there is water enough in the soil both for the support of the crop and for the success of nitrification. Doubtless, surface tillage of any kind is useful, in that it permits air to enter the soil more freely than it could before, not only to promote nitrification, but in order that oxygen may act upon the soil and upon the roots of the crop.

Spring Droughts show the Value of Deep Tillage.

The importance of having not merely a deep soil for the rain-water bed, but perfect capillary connection between this rain-water bed and the standing room of the crop, was well illustrated in Eastern Massachusetts during a somewhat remarkable drought which occurred in 1873. The peculiarity of this drought was that it came very early in the season, viz. in May and June. The nights were cool all the while and the days warm, though not actually hot, and there was plenty of water in the ground. The ground-water stood at a high level all the while, but it was noticeable that crops upon newly broken land suffered very much, while those upon land that had long been tilled did not suffer.

It was plain that in the well-tilled land there was good capillary connection from below upward, and that a great deal of water was lifted by the capillary force. The absence of such power in the newly broken land was an enormous disadvantage to that land; and from the very first the well-tilled land must have been more nearly in the condition of a moist sponge than the other.

It was noticeable also in that year how white-weed (Leucanthemum) got the upper hand in mowing-fields wherever the grass failed from lack of moisture. But since the farmers were forced to cut their grass for hay unusually early, much of the white weed was put to profit in that it was dried for hay while yet in flower. In that particular year some system of keeping the soil beneath grass sods in a good capillary state would have been of no little value to farmers fortunate enough to have practised it.

At the time of a similar drought which occurred in Sweden, in 1868, A. Müller determined the amounts of moisture that were contained in a variety of soils at different depths, and clearly showed the importance of tilth as a means of supplying water to crops. See his paper in "Die landw. Versuchs-Stationen," 1869, XI. 168.

Summer Tillage should be Shallow.

Some persons seem to find a difficulty in grasping the two conceptions; viz. that while shallow summer tillage helps crops to withstand drought, deep summer tillage may heighten the bad effect of drought, and so do harm, particularly on light land in dry seasons. A writer in the "Country Gentleman" of Dec. 4, 1879, gives a good illustration of the harm of working soil too deeply, in the following words: "Contrary to orders, a field of sweet-corn in light sandy loam was ploughed, instead of being cultivated with the horse-hoe. The plough was run very deeply, and the corn was well earthed up in a hot, dry time. From that day the corn stopped growing. It gradually dried up, and the incipient ears, and even those half grown, withered away."

Manifestly, by the act of ploughing the capillary connection in this particular soil had been most unhappily broken at an improper depth. Whereas, if only the surface of the land had been scratched with a cultivator, moisture would still have been lifted from below to supply the wants of the corn crop, while comparatively little moisture could have escaped into the air by way of wasteful evaporation.

A sensible person would naturally restrict himself to shallow summer tillage anyway, in order to avoid injuring too many of the roots of the crop; for although the roots and rootlets of young plants are very abundant, and much more abundant than the leaves and stems, they all have work to do; and although new rootlets form speedily to replace those which have been injured, such act of replacement calls for the expenditure by the plant of both matter and force which had much better have been devoted to the perfecting of the merchantable part of the crop.

It is not improbable that surface tillage may sometimes do good, in that it prevents the land from getting overheated; for a soil covered with a coating of loose earth could hardly be heated so deeply by the sun's rays in dry summer weather as it would be if the earth were compact.

Of late years it has become customary in many places to harrow winter grain lightly in the spring, i. e. grain which has been sown

broadcast; and to harrow over fields of Indian corn also, plants and all, until the crop has grown to a height of three or four inches. It is found that much good is done in this way, by breaking the crust on the surface of the land, by admitting air to the soil and to the roots, and by killing young weeds, while the crop itself suffers very little from the combing.

Rolling moistens the Surface Soil.

The absolute opposite of surface tillage is seen in the use of the roller upon grass seeds and grain, or when the gardener pats down and "firms" the earth with his hoe, or spade, or foot, or thumb, after planting seeds. The object of this compression of the surface-soil is manifestly to bring moisture to the seeds. To this end, a good capillary connection must be established between that part of the soil where the seeds have been sown and the underlying soil which contains a store of moisture.

An ideal condition of things, which might perhaps be sometimes realized in practice in the case of seeds large enough to bear tolerably deep burying, would be to roll the land firmly after seeding it, and then to scratch the surface slightly with a light harrow or rake; for the rolling would enable capillary water to be lifted to the seeds, while the subsequent harrowing would diminish the waste of water from the land by the evaporation which would occur if the surface were to remain compressed as it was left by the roller.

The significance of compression is well shown by the footmarks which careless workmen leave in hoeing summer crops. Unless a man hoes in such manner that his tracks are covered, that is to say, in case he first stirs the soil and then treads upon the loosened earth, his footprints can readily be traced in dry weather by the weeds that continue to live in these compressed and so moistened places.

As illustrating the great waste of water that may occur from land when the surface is compressed, attention may again be called to the experiments cited on a previous page, which show that under favorable conditions more water may evaporate from wet earth than from a body of actual water.

Mulching.

The process known as "mulching," is well worth studying in connection with the question of capillarity and the surface tillage of land.

A mulch is anything laid upon the surface of the soil in such wise that the evaporation of water from the surface is hindered.

Straw, leaves, sawdust, chips, spent tan bark, old boards, and stones — especially if they are flat, like slates — are all used for mulching. The significance of the process is seen on turning over any old log or stone in a field or pasture, and noting the moist earth beneath it, with its manifold slugs and worms, and all manner of insects that affect moisture.

In experiments reported by Ebermayer, it was found, as the average of several trials made in open fields during the summer months, that 22% more water evaporated from a bed of soil half a foot deep that was kept constantly saturated with water, than from a similar bed of earth that was covered with leaves or moss, such as would naturally collect beneath trees in a forest.

By mulching, a good capillary connection is maintained up to the very surface of the soil, and there the movement of the water is stopped; that is to say, evaporation of water from the surface of the land is checked. The thin surface layer of loosened earth, obtained by hoeing or cultivating, is to all intents and purposes a kind of mulch, imperfect it is true, but tolerably effective nevertheless.

Mulches prevent Puddling.

One very important effect of mulching proper is that it prevents the puddling of the soil by rain, and so retains or preserves whatever of good tilth may have been imparted to the land. There are very few soils that do not become hard and close after having been repeatedly rained upon, unless pains be taken to prevent or destroy the incrustment. As Townsend put it long ago: "If soon after wheat or barley has been sown on what is called a running sand there falls a dashing rain, the sand runs together, that is, it forms a crust, which in a great measure is impervious to air, and scarcely a grain of the corn will grow. Or if, on clay land, during a time of drought, a garden plot is watered and left exposed to the scorching beams of the sun, the ground will bake; that is, the surface will be hardened, and, being thus rendered impervious to air, vegetation ceases. But if the surface has been previously covered with fern leaves, as practised by skilful and attentive gardeners, no such effect will be produced. The plot may be watered, and vegetation will be rapid."

A Scotch farmer recently wrote as follows: "I have always observed, that, where land has been covered during winter with anything, even with stones, it raises a larger crop than that which has been exposed to the weather." He was arguing in favor of top-

dressing land with farmyard manure, and justly insisted on the benefit of such a mulch. The old English practice of leaving manure spread upon clay land in winter is a special instance of the same general idea.

No doubt, mulching is a more effective method of controlling the water supply than surface tillage; but, generally speaking, mulching would cost too much for ordinary farm practice. Of course each farmer must decide for himself anew, in a great variety of cases, what is best to be done. All that a teacher can urge upon the student is that he should bear in mind the principles upon which tillage depends, and consider well his aims, and the best ways of reaching them, in each special instance that may happen to present itself to him in actual field practice.

It should be said, perhaps, that mulches are occasionally made to serve other subsidiary purposes beside the retention of moisture in the soil. Strawberries, for example, growing upon sandy loam, may be hindered from becoming gritty by mulching the vines with tan-bark. It is said that both peas and gooseberries may be shielded to a considerable extent from mildew by mulches that are competent to protect the fruit from the damps of earth. It is true, of course, that such partial protection from the dampness of the soil can serve only as a palliative measure; for the germs of the mildew fungus come from the air, and the air often supplies moisture enough for their rapid development. It would be of interest to determine whether the fungus might not be repelled from gooseberries by supplementing the mulch with small quantities of the vapor of tar or petroleum, or some other appropriate germicide agent.

Significance of Natural Mulches in Woodland.

Some of the good effects of mulching are exhibited very conspicuously by the beds of leaves and moss which collect naturally in woodland. This covering of loose materials aids greatly in helping rain-water to soak into the earth where it falls; for not only is the rain caught and held temporarily by the bed of leaves and the moss, and hindered by them in various ways from flowing off the land, but on passing through the bed of litter the water finds at all times ready opportunity to soak into the soil beneath, because of its open, unpuddled, and uncrusted condition.

Another important advantage in keeping land covered, either by mulches, crops, grass, or trees, is that rains cannot wash the

soil away, as would necessarily occur, and with great rapidity in many situations, if the land were bare.

In a series of Bavarian experiments reported by Ebermayer, it was found that, a covering of loose litter permitted much more water to soak into the soil than could pass through grass sod; and it is evident that, as regards the reception of rain-water, leaves, moss, straw, sawdust, tan-bark, or eel-grass will serve a much better purpose when used for mulching, than can be served by inverted sods or boards or stones, although either of these last might perhaps be a more potent agent than the loose litter for preventing the drying out of water from the land.

But it was noticed when a bed of spongy litter thicker than 1½ or 2 feet was used, such as sometimes collects in woodland under coniferous trees, that most of the rain-water was held by this thick layer of loose materials, and evaporated off from it in due course; it was only in heavy rains that a part of the water soaked through so thick a bed of litter into the soil proper.

In the spring, when the great masses of snow which have collected in the forest slowly melt, large quantities of water soak into the earth and saturate it completely, and this result is favored by the fact that the soil has been not a little protected from freezing during the winter by the layer of leaves upon its surface.

Speaking in general terms, comparatively little water flows off from the surface of the land in wooded districts, while enormous quantities of water soak into and through the soil slowly. Thus it happens that land covered with forests may be kept continually moist simply by its power of catching and holding rain-water, and of retarding the movements of water in divers ways. In dry summer weather, moreover, a loose covering of leaves or pine needles will greatly hinder evaporation from the surface soil.

In spite of the enormous quantities of water which must be pumped out of the soil by trees and transpired as vapor from their leaves, it is seen to be true, generally speaking, that the power of soils covered with forest to receive and hold water is so great, that, wherever considerable tracts of land are covered with trees, the whole region may be moister than it would be if the trees were absent.

In the wooded portions of Northern New England, it is evident enough that both the abundance and the coldness of the ground-water have no inconsiderable influence on the coolness of the sum-

mers, especially on the coolness of the nights. The country becomes drier and hotter when cleared, not only because much water now drains away from it at once, but because the ground-water tends to dry out of the surface soil rapidly, and because the temperature of the ground-water naturally increases somewhat in proportion as woods are more completely removed from the land.

From the Bavarian experiments, it appears that a considerably smaller portion of the yearly rainfall actually comes to the ground in a forest than falls upon an open field, because much of the water, particularly when the showers are light, evaporates from the tree tops to which it has clung. But in case the soil of the forest is strewn with leaves, this mulch, taken in connection with the shelter afforded by the trees, so lessens the evaporation from the soil that the water which never came to the earth because of the tree tops is more than compensated for by the increased soakage into the earth. It appeared that, while on the average 26% less water reached drain-gauges that were kept in the Bavarian forests than fell upon open fields,[1] absolutely more water could percolate through leaf-covered soil situated in a forest, than percolated into the soils of fields.

In general, the difference between percolation through columns of soil placed in fields and forests was most marked at a depth of 2 feet. Of the water that fell on the fields, 50% percolated to a depth of 2 feet, while 77% of the water which fell on leaf-covered soil kept in a forest percolated to that depth. At a depth of one foot the figures were 54% and 74% respectively, and in case the soil kept in the forest was not leaf-strewn the percolation was 67% at the depth of one foot. This is to say, 20 and 27%, or a mean of 24%, more of the precipitated water percolated in leaf-strewn soil kept in woodland than in soils kept in fields, in spite of the great general fact that 26% less water reached the earth in the forest than in the field.

In consonance with this approximate balancing of evaporation in the fields and soakage in the woods, it appeared that there was no great difference between the absolute amounts of water that percolated in a year at a depth of 4 feet in drain-gauges that were kept

[1] The amount of the evaporation from foliage naturally varied considerably, according to the kinds of trees, and whether they stood more or less thickly. In one instance where the rain-gauge was purposely put beneath a particularly thick grove of pines only 59% of the yearly rain-water reached the gauge. These trials are far from conclusive, however, since no account was taken of water that may reach the ground by running down the tree trunks.

in the fields and in the woods. The figures were 2,623 c. in. and 2,235 c. in. respectively for gauges exposing a surface one square foot in area.

In general, it was found that the shade and shelter due to the trees themselves, together with the protecting influence of the bed of leaves or moss beneath the trees, work effectively to diminish loss of water by evaporation from the surface soil of a forest; though in wet years and in times of rain the influence of the leaf-bed in hindering evaporation was much less marked than it was in dry seasons. On the average, it was found that during the summer months evaporation from a bed of earth that was kept saturated with moisture in a forest was 84 to 86% less than evaporation from beds of uncovered saturated soil in open fields.

The shade and shelter cast by the trees themselves were competent to make the evaporation from the saturated soil 62% less than it was in open fields, and the leaf-bed diminished the evaporation 22% more. From leaf-covered saturated soil kept in woodland, it was found that evaporation was 60% less than from a bed similarly situated but not covered with leaves.

Like the experiments on evaporation, these Bavarian experiments on percolation were made with great care at several different stations, at each of which the influence of field and forest and that of mulch and no mulch were contrasted. The drain-gauges employed were rectangular, and each of them was one Parisian square foot in area. They were made of sheet zinc, and were so constructed and arranged that observations were made at 1, 2, and 4 feet (Parisian). The gauges were filled with earth, and sunk in the ground almost, but not quite, to their topmost rims, i. e. they were fixed so that no surface water could flow into them from the surrounding land.

It is to be noticed particularly, however, that in no instance was the earth in these gauges subjected to the conditions which really exist in the soil of a forest, since no roots of trees had access to the soil in the gauges. Unlike many of the experiments upon sod land such as have been reported on a previous page, the Bavarian drain-gauges were wholly shielded from the pumping action of the roots of plants.

Through drain-gauges sunk in open fields the largest amounts of water percolated in winter. Indeed, thanks to the low rate of evaporation at this season, almost the whole of the rainfall passed

through the drain-gauges. At this season the soil of the fields was more highly charged with water than at any other time; then followed in order spring, autumn, and summer. But the differences between summer and winter were very large.

Taking the six colder months of the year, the percentage of percolation water at the depth of 4 feet in the open fields was about 3 times larger than it was in the six warmer months; while in woodland gauges covered with litter, only $\frac{1}{7}$ more of the rainfall percolated 1 and 2 feet, and $\frac{1}{6}$ more percolated 4 feet, in the six winter months than in the six summer months. In woodland gauges not covered with litter about $\frac{1}{2}$ more of the rainfall percolated 1 foot in winter than in summer. Again, while in the winter half-year $\frac{3}{4}$ of the rainfall percolated 2 feet in open fields, and almost $\frac{8}{10}$ in woodland gauges covered with litter, only $\frac{1}{4}$ of the rainfall percolated to this depth in summer in the fields, and rather more than $\frac{7}{10}$ in the woodland.

In summer, properly so called, the quantities of water that percolated in the fields 1, 2, and 4 feet were, respectively, $3\frac{1}{2}$, $4\frac{1}{2}$, and $7\frac{1}{2}$ times smaller than in winter, because of the more abundant evaporation from the surface soil in summer.

Inasmuch as, both in winter and summer, the amounts of rain-water that fell upon the drain-gauges in the open fields were absolutely larger than those which fell upon the woodland gauges, more water naturally percolated through the deep gauges in the open fields during the winter months than passed through those in the woodland, because at this time of year the influence of the trees and the litter in checking evaporation is of very little importance. It appeared in winter, indeed, that beds of litter placed upon the drain-gauges had little or no influence upon the amount of percolation.

In spring, the increased rate of evaporation in the open fields was speedily felt at the drain-gauges in the diminished rate of percolation. But through the woodland gauges, on the contrary, the largest amount of percolation was in spring, when the snow was slowly melting. At this season the differences between the field and forest gauges were least clearly marked. But it was noticeable that in spring more water, both absolutely and relatively speaking, passed through the 4 feet gauges that were kept in the woods than passed through them during the winter months.

In summer, when evaporation from the surface soil is most rapid, percolation through drain-gauges kept in the woods was absolutely

much larger than through gauges placed in open fields. The sheltering influence of the woodland was more marked at this season than at any other. From May to September (inclusive) there percolated to depths of 1, 2, and 4 feet, respectively, the following per cent of the rainfall, through drain-gauges kept

	1 ft.	2 ft.	4 ft.
Covered with litter in the woods	73	74	58
Without litter " "	53	. .	. .
In open fields	17	16	17

That is to say, during these warm months 3 times as much water percolated 1 foot through the unmulched woodland drain-gauges; $4\frac{1}{2}$ times as much water percolated 1 and 2 feet, and $3\frac{1}{2}$ times as much percolated 4 feet, through mulched woodland gauges, as passed through unmulched gauges in the open fields. In July, August, and September, evaporation was so rapid in the open fields that at several of the stations no water, or next to none, passed through the field drain-gauges, while in the woodland gauges percolation did not cease, — not even in July. In this month enormous differences were observed in the rates of percolation in the field and forest gauges. The quantities of water that percolated through the woodland gauges at depths of 1, 2, and 4 feet were respectively 5 times, 10 times, and 5 times larger than those which percolated in the open fields.

In summer more than half the rain which fell on the bare woodland gauges percolated 1 foot; and in the gauges that were covered with litter $\frac{3}{4}$ of the rainfall percolated 1 foot, $\frac{2}{3}$ percolated 2 feet, and $\frac{1}{3}$ percolated 4 feet, while through gauges in the open fields hardly $\frac{1}{5}$, $\frac{1}{7}$, and $\frac{1}{10}$ part of the rainfall percolated at depths of 1, 2, and 4 feet respectively.

When no plants are allowed to grow upon the gauges, it appears that so large a part of the summer rainfall evaporates out of the upper layers of the soil of the field gauges, that there is very little left to percolate downward; whereas, when the surface soil is mulched and shaded, as in woodland, a very considerable portion of the rainfall can soak into the lower layers of the earth.

Though less water percolated through the woodland gauges from May to September than during the other months of the year, the differences were not so well marked as in the case of the field gauges. More water percolated at a depth of one foot in the woodland gauges from April to September, both when they were and were not mulched, than passed through the field gauges. But from

October to March (inclusive) the reverse of this was true, and the field gauges percolated more freely than those in the woods. Taking the whole year, more water percolated through the gauges that were covered with litter than through those which were bare, though the advantage of the mulch was most conspicuous in hot summer weather. Almost as much again water passed through the woodland gauges that were covered with litter, during the growing season, — i. e. during the warmer part of the year, — as passed through the field gauges; and 20% more of the rainfall percolated at a depth of one foot during the summer months through the litter-covered woodland gauges than through those which were bare.

During most months of the year less water dropped at a depth of 2 feet than at a depth of 1 foot from gauges in open fields, while in the mulched woodland gauges the soil held more water at 2 feet than at 1 foot during most months. As a general average, the earth in the bare field gauges was drier at a depth of 4 feet than at a depth of 1 foot; and in the mulched woodland gauges, also, during most months in the year, less water dropped from the soil at a depth of 4 feet than dropped at lesser depths. Usually, the woodland gauges held most water at a depth of 2 feet.

In autumn the percolation was found to be somewhat similar to what it was in the spring, though, since evaporation is rather stronger in autumn, percolation is proportionally weaker.

In the following table are given the average amounts of percolation at the different seasons of the year, as determined by the Bavarian observers. The statements are in terms of per cent of the water which came to the ground, as rain or snow, at the several seasons. There passed through drain-gauges that were

	Placed in open Fields, uncovered.			Placed in Woodlands. No Leaves.	Covered with Leaves.		
	foot.	2 feet.	4 feet.	1 foot.	1 foot.	2 feet.	4 feet.
Winter (Dec., Jan., and Feb.) . .	94	89	99	91	94	97	63
Spring	55	56	64	70	81	81	83
Summer	19	14	11	52	72	65	36
July, by itself	11	6	7	. .	58	61	34
Autumn	54	51	49	60	60	68	54
Winter half-year (Oct. to March, inclusive)	72	67	76	80	86	87	73
Summer half-year (April to Sept., inclusive)	23	24	24	57	75	76	62
Difference	49	43	52	23	11	11	11

CHAPTER VII.

PRELIMINARY CONSIDERATIONS RELATING TO MANURES.

THERE is an experiment made many years ago by the French chemist Boussingault that is well worth considering. Boussingault washed three flower-pots carefully; he heated them to redness in a fire, and filled each of them with a mixture of fragments of recently burnt bricks and quartz sand. Both the brick and the sand were thoroughly washed with distilled water, and then calcined before being put in the pots.

To the soil in Pot 1, or rather to the contents of Pot 1, nothing was added but two seeds of the small sunflower (Helianthus argophyllus), and distilled water, from time to time, as the plants needed watering. Into the soil of Pot 2 small quantities of phosphate of lime (bone-ashes in fact), of the ashes of hay, and of nitrate of potash, were stirred. Pot 3 received the same dose of salts as the second pot, excepting that, instead of nitrate of potash, there was added carbonate of potash in quantity sufficient to bring in just as much potash as was contained in the nitrate of potash of the second pot.

Two seeds of the sunflower were planted in each of the pots on the 5th of July; the pots were placed in the open air under a glass roof to protect them from rain, and were carefully watered with distilled water, free from ammonia, but containing about $\frac{1}{4}$ part of its volume of carbonic acid.

On the 20th of September the plants ceased to grow, and on the 30th of that month their heights were to one another as the lengths of the lines here printed:

No. 1.
" 3.
" 2.

Figures of the plants are given in "How Crops Feed," p. 271, from which it appears that, while the plants in Pot 2 grew luxuriantly, the plants in Pots 1 and 3 were miserable dwarfs. Each of these dwarf plants weighed no more than 4 or 5 times as much as the seed from which it sprung, while the vigorous crop obtained

from the soil that had been fully manured weighed almost 200 times as much as the seed.

In 86 Days the Plants gained Grams of Carbon.	Nitrogen.	Weight of the dry Crop, the Seeds being taken as 1.	Vegetable Matter formed, in Grams.	In the Pot which received
0.114	0.0023	3.6	0.285	No manure.
8.444	0.1666	198.3	21.111	Ashes and nitrate of potash.
0.156	0.0027	4.6	0.391	Ashes and carbonate of potash.

This simple experiment is really a compendious treatise on the theory and practice of manuring. To make the illustration complete, there is needed only one other pot, to the soil of which nitrate of potash alone has been added, without any ashes or bone-earth; and numerous experiments have shown that such a pot would have given no better crop than Pot 1 or Pot 3, provided the sand and brick-dust used contained no assimilable ash ingredients.

It is but fair to say, that the experiment just described was made merely to show the power of nitrates to supply nitrogen to plants; but it so well illustrates the whole matter of feeding plants, that the general significance of it cannot be too strongly insisted upon.

Plants need to be supplied with all Kinds of Food.

Whenever a seed germinates, as in Pots 1 and 3, or in the suppositious Pot 4, in a soil totally destitute either of any one or of all the ash ingredients and of the nitrogen compounds which are essential for vegetable growth, the plant will grow only at the expense of the substances contained in the seeds, or afterwards at its own expense for a brief period. It will soon cease to increase in weight, and after a while it will die. In order that any plant shall flourish, it must have continual access to all kinds of food, as in pot No. 2.

It is impossible to lay too much stress on this fundamental conception, that in order that crops may succeed they must be fully supplied with ash ingredients, and with nitrogen compounds from the soil. And it is desirable that the student should immediately seek to apply this knowledge to the explanation of certain familiar facts in agricultural and horticultural practice.

Ordinary Loams contain all Kinds of Plant-Food.

If the sunflower seeds of Pots 1 and 3 had been sown in ordinary soil and then watered with rain-water, or, better, with spring or river water, the plants would have continued to grow well enough after the matter of the seed was exhausted, and would have come to maturity somewhat like those in Pot 2, though perhaps less completely.

Indeed, it is a matter of common observation and experience, that a plant left to itself in the field can obtain food from almost any ordinary soil that is duly supplied with air and water, whence it appears that ordinary soils, like the artificial mixture in Boussingault's Pot 2, contain naturally more or less of all the constituents of plant food; and that the points specially in need of being studied as to soils relate to the amounts of this natural food which may occur in them, to the state in which it exists, and to the means by which plants are enabled to obtain it.

It is evident, moreover, from the experiment above cited, that by putting certain chemical substances upon a soil its character may readily be changed, and its power of feeding crops increased. In like manner, it is easy to control or modify to a very considerable extent the action of water in or upon a soil, although as regards the atmosphere in which a field plant grows we have as yet little or no power to check or control its action in any way.

There are upon record many striking instances where soils naturally sterile have suddenly been made fertile by the application to them of plant-food. In the Spanish province of Catalonia, more especially in the vicinity of Barcelona, the soil is said to be principally quartz sand, which is rendered exceedingly productive by means of moderate dressings of dung and copious irrigation. Thanks also to the bright sun and hot climate of the locality, abundant crops of all kinds are grown upon the sand as a result of the treatment above mentioned. So also, in the Belgian Campine, hundreds of acres of sterile sand have been brought into a condition of high fertility by the application of guano and water. Just below the city of Edinburgh there is an astonishingly fertile tract of mowing-land, the soil of which is mere coal ashes and sand; but over this soil the sewage of a part of the city is made to flow. There are many other such cases where mere irrigation with water has produced permanent fertility, as will be explained hereafter.

Soils contain much Inert Matter.

All soils consist for the most part of substances which have no direct or immediate use in feeding the plant. Just as in Boussingault's experiment, so in natural soils there is a mass of inert sand, gravel, and clay, which last is often worse than so much brick-dust, with some small portion of fertilizing matters scattered among the other materials. It is not probable that so much as one part in

a hundred of a good dried soil ever contributes directly to the feeding of the plants which are grown upon it.

The influence of the inert portions of the soil upon the plant depends chiefly upon their relations to moisture and to heat, as has already been explained, and upon the facility with which they disintegrate and change into substances chemically active.

As has been said, soils and rocks are not wholly insoluble in water, particularly not in water such as is found in nature. Indeed, soils ordinarily contain so large a proportion of constituents that are not absolutely insoluble but only difficultly soluble, as the term is, that it is quite impossible to determine accurately and precisely how much of a given sample of soil is soluble in water, for new portions of the soil continue to dissolve as long as new quantities of water are poured upon it. It is true, that much more matter is dissolved from the soil during the earlier stages of this leaching process than afterwards, and that by percolating a soil with small definite volumes of water it is possible to push out and collect the matters that dissolve easiest, as well as whatever was actually in solution in the soil at the beginning. It may be said of such solutions, obtained by leaching loam with comparatively small volumes of water, that they contain the matters which were unquestionably at the service of plants at the moment when the earth was experimented upon; and, in point of fact, everything needed for the growth of plants has been found in such solutions, though naturally enough some of the constituents of plant-food were present in them in extremely small proportion.

Extracts of Earth.

Several different methods of experimenting have been resorted to in order to determine what matters can be dissolved from the soil by water, and for the purpose of gaining an idea as to whether the soil-water is or is not capable of supplying plants with food.

One way of obtaining knowledge upon this point is, to soak a quantity of the soil for several hours in distilled water, to pour off the water from time to time into a special dish, and to replace it with fresh portions of water that are mixed with the earth. Verdeil and Risler experimented long ago in this way, and their experiments have been tabulated by Johnson in "How Crops Feed," p. 310.

By evaporating to dryness the solutions obtained from various kinds of loams, these investigators got residues that contained from

30 to 67% of ash ingredients, and from 33 to 70% of organic and volatile matters. In the ashes they found varying quantities, often large, of sulphate, carbonate, and phosphate of lime, together with compounds of potash, soda, and iron, and sometimes magnesia and alumina.

Eichhorn, working in a way analogous to that of Verdeil, went so far as to assert that capillary water which had been left ten days in contact with undunged garden loam contained as much matter in solution as would suffice for the requirements of a good crop. But Wunder, on repeating this experiment, denied that enough matters are dissolved to support an agricultural crop.

In general, it appears that 1,000 parts of pure water can dissolve out of ordinary soils from ½ to 1½ parts of mixed organic and mineral matters. Poor sandy soils generally yield the minimum quantity, while very rich soils, especially if they have been recently and heavily manured, sometimes give the maximum amount. Usually these solutions contain a considerable proportion of organic matter, viz. as much as will amount to ⅓ or ½ the weight of all the material that has been dissolved. From wet peats and peaty soils 1,000 parts of water may dissolve as much as from 4 to 14 parts of matter, but it is chiefly organic, and is poor in respect to several important kinds of plant-food, notably phosphoric acid.

Several experimenters have been at pains to determine how much of each of the matters needed by plants can be extracted from a soil by water, as may be seen in the tables of analyses given on page 311 of "How Crops Feed."

Water from Wells and Field Drains.

Another way of investigating the problem is to collect and analyze the waters of wells and of field drains, and that which has soaked out from drain-gauges. Highly interesting results have been obtained in this way, for it appears that, with the exception of nitrates and lime, only very small quantities of the really useful constituents of plant-food pass off in the drain-water. See "How Crops Feed," pp. 313–315.[1] From ⅓ to ½ lb. of matter is usually found dissolved in each 1,000 parts of drain-water. The proportions of some of the more prominent substances in 1,000 parts of the water may be stated as follows: organic matter, 0.01 to 0.10; nitric acid, 0.05 to 0.20; lime, 0.02 to 0.10; potash, phosphoric

[1] Compare Heiden's tables, in his "Düngerlehre," I. 294, 295.

acid, and ammonia, traces; sulphuric acid, 0.02 to 0.07; soda, 0.01 to 0.03; magnesia, 0.001 to 0.03.

But, as Mulder has suggested, the solutions that pass out from a drain-gauge contain only those things which can be carried down now and then by the excess of rain when it has fallen in quantities larger than the soil can hold. Such solutions do not really represent the dissolved matters which are offered to crops by the soil-water during the growing season. Most of the substances that are carried down by the percolation of rain-water towards the bottom of the drain-gauge in wet weather do not actually escape from the soil; and they are drawn up again towards the surface of the land by capillary action after the rain-water has ceased to soak downward.

The results of these numerous investigations lead to the conviction that water is capable of dissolving from the soil minute quantities of everything which plants need. It is true, that, in some of the analyses which have been reported, the quantities of phosphoric acid, of magnesia, of sulphuric acid, and of chlorine in the solutions have been so small that they seemed to elude the chemist's tests. But the tests, in the cases of phosphoric acid and magnesia at least, were not very delicate, and there is every reason to believe that these substances could always have been detected, as they have been usually, if only a larger quantity of soil had been leached, or if a larger portion of the solution, or of the drain-water, had been evaporated before applying the tests. The diversity of the results actually obtained hitherto by different experimenters points clearly to this conclusion.

Plants can be grown in Well-Water.

There is, moreover, another item of experimental evidence which supports this view, or rather proves it, — the power, namely, of plants to flourish in well-water; as has been shown not only by scientific experiments in water culture, but by the familiar practice in domestic horticulture of growing seeds and cuttings of various plants in jars of water.

Heinrich filled boxes that were 42½ centimetres deep and 1,000 square centimetres in superficial area with gravel and sterile sand, in which were sown seeds of various grasses, clovers, and vegetables, and he watered the plants with spring-water applied in various quantities. Generally speaking, the crops were larger in proportion as more water had been given to them, as will appear from the following table.

No. of cc. Water poured upon the Land each Day.	Average Weight of the Crops harvested, in Grams.
100	35
200	44
300	57
400	84
500	110
600	138
700	148
800	161
900	156
1000	170

Birner and Lucanus grew an excellent crop of oats by way of water culture in water taken from an ordinary well, and supplied at the rate of a quart a week to each of the plants. As compared with oats grown by them in garden loam, and in ordinary field culture, the results of the experiment were as follows:

Grown in	Weight in Grams of an average Plant dried.	Weight of the dry Grain.	The Seed being taken as 1, the dry Crop weighed
Garden loam	5.27	1.23	193
Field	1.75	0.63	64
Well-water	2.91	1.25	106

It appeared that as much grain was got on the plant grown in well-water as from that grown in the garden loam, and twice as much as was got from the field-grown plant. The plants grown in water were larger and heavier than those grown in the field.

Heiden makes the capital point, that it cannot be strictly correct to regard the water of wells and field drains as comparable, in respect to chemical composition, with the water in the soil proper; i. e. the loam at the surface of the field for that portion of the rain-water that finally escapes from the drains has to pass through several feet of subsoil after it has soaked out of the surface loam, and — in accordance with the laws that regulate the retention of fertilizing matters, as will be explained directly — the subsoil stands ready to absorb and fix potash, ammonia, phosphoric acid, etc., to say nothing of the speedy absorption by plant roots of matters from the water, as it passes by them.

Selective Power of Plants.

Attention has already been called to the fact, that the food which enters the plant from the soil probably does so in the form of an aqueous solution, and that the solution is moved by the forces of liquid diffusion and osmose. There remains to be considered, at

somewhat greater length than was convenient before, the so-called "selective power" of the plant for special kinds of food. For although the manner in which the plant takes from the soil-water the things it needs may admit of a tolerably satisfactory explanation, it is not so plain at first sight how the plant can reject matters which it does not need; and yet it is extremely probable that the power of exclusion is nothing more than a simple consequence of the law of liquid diffusion.

If a solution of nitre, for example, be brought in contact with a solution of sugar, the two substances will diffuse until they are mixed equally throughout the entire liquid, and then the movement will come to rest; and it may be supposed that the same thing would happen in two contiguous plant cells, if one were charged with the solution of nitre and the other with that of the sugar.

In this view of the matter, nitrate of potash or any other substance dissolved in the soil-water must necessarily diffuse into the root cells of a plant so long as the liquid in the root cells contains less of the nitrate than the soil-water contains. But the moment the liquid in the root cells comes to contain as much of the nitrate of potash as the soil-water contains, no more of that special substance can enter the cell, unless indeed a portion of it should be transferred to the adjacent cells, and room thus made for the admission of a new quantity.

Naturally enough, the diffusion of any substance from cell to cell within the plant may be conceived of as going on in the same way as that of the soil-water into a single root cell.

In one word, whenever two miscible solutions of unlike composition are brought into contact, there diffusion will set in and proceed until an equilibrium has been established. Hence any harmless soluble substance not needed by the plant will enter freely until the sap contains just as much of it as the soil-water contains, and then matters will come to a standstill, so far as that particular substance is concerned.

But with substances such as potash or phosphoric acid, for example, which are really consumed by the plant and incorporated in its structure, new quantities must constantly diffuse into the plant to take the place of those which have been removed from the sap.

As Pfeiffer has suggested, the matter may be illustrated by supposing that a bladder full of water has been immersed in a dilute

solution of sulphate of copper, in which event the water and the copper solution will diffuse into one another until an equilibrium has been reached, and the solution is equally strong inside and outside the bladder. But in case a piece of metallic zinc were placed in the water of the bladder, then metallic copper would be precipitated upon the zinc as soon as any of the solution of the copper salt reached the zinc, and would consequently be withdrawn from the solution. This precipitation of copper would continue as long as any of the zinc remained undissolved, and room would in this way continually be made for the admission into the bladder of new supplies of the copper salt. Meanwhile sulphate of zinc would be formed continually, and would diffuse outward until all the copper had been precipitated upon the zinc, and the solution of sulphate of zinc had reached the same degree of concentration inside and outside the bladder walls. This reaction would go forward withal, no matter how dilute the solution of the copper salt might be, so that in the course of time much copper might accumulate in one spot, by precipitation upon the zinc, in case a continuous supply of the dilute cupric solution were maintained outside the bladder.

Some Plants take in Silica.

A familiar illustration of osmotic exclusion, as well as of osmotic entrance, of a useless substance, is seen in the case of silica, which is kept out by some kinds of plants and admitted by other kinds. It is found that the grasses and grain-bearing plants take in much more silica than clover and other leguminous plants do. But when the two kinds of plants grow side by side, so that their roots commingle in the same soil-water, it is fair enough to suppose that silica may at first enter both kinds of plants alike, and that the sap of both may soon be brought to the same state of saturation (as regards silica) that exists in the soil-water.

But the grasses deposit a part of this silica in their leaves and stems so that new portions of it can come into the sap from the soil. The clover, on the other hand, uses but little silica, so that the sap simply remains saturated, so to say, with that substance, from first to last, and no new portion of it is received from without. Practically it is found that while 1,000 lb. of grass may contain 7 lb. of silica, 1,000 lb. of red clover contain less than half a pound.

Here, as elsewhere, demand, or rather consumption, creates supply. Thus, while on the the one hand the water of the soil will diffuse rapidly into the sap of the clover plant to make good the

loss of the large quantities of that liquid which are incessantly exhaled from the leaves into the air, the diffusion of silica will necessarily be slow since only a little of it is consumed.

In the same way that a plant can select its food in this sense, so can it reject any saline or other soluble crystalloid substance for which it has no use, and which may have been formed within it in excess of the amount contained in the soil-water.

Chemical Substances decomposed by Plant Roots.

It is known, from experiments made by way of water culture, that plants vegetating in dilute solutions of various salts readily decompose them. Nitrate of potash, for example, is often broken up in this way, in such wise that, while the whole of the nitrogen goes into the plant, a part of the potash is left behind in the liquid. So too chloride of ammonium is split up, some of its chlorine remaining in the liquid in the form of chlorhydric acid.

There is nothing particularly strange in this fact, since solutions of many salts — such, for example, as alum and acid sulphate of potassium — may be decomposed by mere diffusion in water, and still more readily by osmose through porous films.

But it is evident that active chemical agents like caustic potash and muriatic acid cannot thus be set free in the soil without acting in some way upon it. It is altogether probable that the chemicals excluded by the plant in this way conduce to its growth, by dissolving food for it from the earth immediately around the roots. It is well to remember that one of the chief difficulties with which the method of experimenting by water culture has to contend is this exclusion of corrosive substances by the roots of plants; and that, where there is no soil to absorb and neutralize the excluded matters, the roots themselves are often acted on and destroyed.

Roots corrode Rocks.

An important set of experiments by Dietrich, bearing upon the question of exclusion, were conducted as follows. The idea was to see how much soluble matter could finally be extracted from two samples of powdered rock, one sample being kept free from any vegetation while the other was made to support a crop of plants.

Samples of crushed basalt and of coarsely powdered sandstone were thoroughly washed with distilled water. Each of the samples was then divided into nine equal portions, each of about 10 lb. weight. Two pots full of each of the kinds of rock were left unplanted, while weighed quantities of seeds of various plants, such

as peas, buckwheat, lupines, etc., were planted in the other seven pots.

The composition of each of the kinds of seeds employed was determined by analysis. Dust was excluded from the pots by means of paper covers, and by layers of cotton batting. All the samples of rock were watered alike with distilled water, and kept moist during the entire experiment. After its close the vegetable remains were removed, and each sample of rock was washed with 2 litres of water that contained a hundredth part of nitric acid.

It was found that, in spite of the fact that considerable quantities of mineral matter had been consumed by the plants and removed in them, more soluble matter was obtained in every instance from the samples of rock upon which plants had grown, than from those which were left unplanted. The amount of matter made soluble by the action of the roots of the following plants was : —

	In the Sandstone. grm.	In the Basalt. grm.
3 lupine plants	0.6080	0.7492
3 pea	0.4807	0.7132
20 spurry	0.2678	0.3649
10 buckwheat	0.2322	0.3274
4 vetch	0.2212	0.2514
8 wheat	0.0272	0.1958
8 rye	0.0137	0.1316

Although the basalt was more freely acted upon than the sandstone, it was nevertheless true that the latter bore rather better plants, and plants that contained a larger percentage of mineral matters.

It appeared plainly enough that the roots of the leguminous plants, especially those of the lupine, exerted a more powerful solving influence than those of grain-bearing plants like wheat and rye ; but in every case the decomposing power of the roots was distinct and unquestionable. It is interesting to observe as one result of this corrosion of the soil by acids exuded from the roots, that the constituents of the soil must be set free directly in contact with the roots ; that is to say, at the very places where they can be most readily absorbed and utilized by the plant.

Experiments to illustrate Corrosion by Roots.

Several different experimenters have studied in the laboratory the action of slightly acidulated water, kept on one side of a membrane, upon solid matters that were lying outside the membrane

and in contact with it. First among them, Schumacher noticed that carbonate of lime, when separated from carbonic acid water by a membrane, could still be dissolved by the liquid, and so brought through the membrane by means of osmotic action. Then Zöller, having filled several glass vessels with distilled water, to which he had added enough acid of one kind or another to impart an acid reaction, tied pieces of bladder across the mouths of the vases in contact with the acidulated water, and he strewed upon the bladder phosphate of lime and the insoluble double phosphate of magnesia and ammonia. Even after a very short time he was able to detect phosphoric acid, lime, magnesia, and ammonia in the liquid, i. e. all the constituents of the insoluble matters upon which he was experimenting.

Heiden repeated these trials and obtained similar results. Among other things he tried phosphate and carbonate of lime against water acidulated with acetic acid, and for the sake of comparison he tried at the same time sulphate of lime against pure water. In all these instances the action was similar; i. e. enough of the acid liquid passed continually through the membranes to dissolve the matters that had been laid upon them, and the dissolved matters diffused back in their turn through the membrane into the store of liquid.

It is a familiar fact, that the juices of many plants are highly acid, and it has been shown indeed by Knop and by Stohmann that fresh rootlets give an acid reaction when they are pressed against litmus paper, so that it is certain that, beside the carbonic acid which roots are known to exude, there are within the plant agents fully competent to dissolve food from the soil in the manner indicated by the experiments just cited, and to the extent shown by the experiments of Dietrich.

A neat illustration of the acidity of roots has been suggested by Cohn, who laid grains of barley to germinate on moistened litmus paper, and noticed that, wherever the rootlets cling to the paper, the color of it is changed from blue to red. On looking at the other side of the sheet of paper the course of the rootlets may be seen plainly traced in red lines upon the blue ground. It is to be remembered that this action by chemical corrosion through the roots is incessant and continuous.

This matter has been tested in still another way. Several chemists have grown plants successfully in soils naturally sterile, that had been purposely saturated with the various substances needed

as plant-food and afterwards very thoroughly washed in order to remove everything that was soluble in mere water. For example, Stohmann, having soaked some peat in barnyard liquor during several hours, subsequently washed the peat with water for three weeks, until the washings no longer contained anything appreciable in solution. In one portion of this saturated, washed peat he grew Indian corn directly, as contrasted with the growth of corn in the original barren peat, and for the sake of still greater certainty he prepared two mixtures by commingling some of the saturated with the simple peat, and he grew corn in these mixtures also. The following weights of air-dried plants were harvested :—

	Simple Peat.	Saturated Peat.	$\frac{1}{3}$ Saturated and $\frac{2}{3}$ Simple.	$\frac{2}{3}$ Saturated and $\frac{1}{3}$ Simple.
Total weight of crop	17.5	836	282.0	368.0
Weight of grain	0.0	153	1.5	15.5

Whence it appears, again, that matters exuded from plant roots must have power to dissolve from the soil many kinds of food that are insoluble in mere water.

Yet again, it is to the acid juices that are exuded from the roots of plants that must be accredited the lines and furrows which are often to be seen upon bones, and upon pebbles of limestone and other rocks with which roots have been in contact in the soil. A common way of exhibiting this action is to sow seeds in a small heap of sand or sawdust placed upon a slab of marble. After the seeds have germinated, their roots will cling to the marble, and corrode it so that, on removing the sand and roots after a time, the imprint of the latter will be found plainly visible etched upon the slab.

Roots develop rapidly when in Contact with Food.

It does not appear that plants have any selective power, in the sense that they can take in food in any other way than by osmotic action. Nor is it true that the roots of plants can start off at will, like the legs of animals, in the direction of any given mass of nourishment. But it is most distinctly true, that, when the rootlets come in contact with earth or water in which there is an abundance of plant-food, they will be developed there with far greater rapidity than in the neighboring portions of earth in which less food is to be found. The roots of a plant thus often get a distinct bias in one direction, almost as if they had intentionally proceeded in that direction from the first.

Thus it is that the roots of sainfoin are said to burrow for lime, and the roots of grape-vines and of many trees, such as willows, alders, poplars, elms, and ashes, and even the roots of ordinary plants, such as turnips and clover, are found running at large in sewers and house drains. Drains have been found stopped with grass roots at a depth of 2 feet, with horseradish roots at a depth of 7 feet, with the roots of gorse at 14 feet, and with those of an elm tree at a depth of 9 feet, 50 yards distant from the tree. In all these cases it is to be presumed that the drains contained constantly more or less water. Probably they were conduits of water, and constantly in operation.

Experiments showing how Roots develop when fed.

Corenwinder planted a number of young beets in a circle two feet in diameter, and pushed down a bit of oil-cake an inch or so into the soil at the centre of the circle. Some months afterwards he found that several of the beets had sent out horizontal roots as far as the oil-cake, which was covered with a complete mat of capillary roots. One or two of these side roots had passed through a course of 16 inches before reaching the oil-cake.

Sprengel experimented upon this subject long ago as follows. By means of thin boards he made six tight compartments in a tub 18 inches high and 14 inches in diameter, and filled them all with garden earth. No addition was made to the earth of one of the compartments; but in one he placed a mixture of potash, gypsum, and bone-meal; in another, some carbonate of lime; and in the others, bone-meal, gypsum, and common salt respectively. Upon the middle of this first tub he placed another, 12 inches high and 10 inches in diameter, that had no bottom. This second tub was filled with garden earth, in which were set out a number of clover plants that had roots six inches long. These plants were watered with rain-water until they were fully grown, when it was found that the largest and most abundant roots had grown in the compartments that contained bone-meal, while the smallest and feeblest were in the compartment that contained the common salt.

Somewhat similar experiments have been tried by Nobbe. A large quantity of a heavy clay soil was sifted and divided into two equal portions. One of these portions was treated with various saline solutions, used in such quantities that the earth should be $\frac{1}{10}$ saturated with potash, soda, and phosphoric acid, and $\frac{1}{4}$ saturated with ammonia. Four large boxes, $2\frac{3}{4}$ feet deep, were filled in such wise that

No. I. contained nothing but the fertilized earth.
" II. contained a ½-foot layer of the fertilized earth above a deep layer of crude earth.
" III. had 2 feet of fertilized earth at the bottom of the box, and crude earth above.
" IV. contained nothing but the crude earth.

Red-clover seeds were sown in May, and at the end of a year the plants were thinned out so that 48 were left in each box. During the subsequent 14 months some of the plants died, especially in the unmanured soils, but there were harvested by several instalments the following quantities of dry hay, and finally of dry roots, in grams: —

		Hay.	Dry Roots.
I.	Wholly fertilized	592	60
II.	Fertilized on top	615	31
III.	Fertilized below	439	26
IV.	No fertilization	431	30

The roots from the different boxes differed very much in appearance. Both the unmanured and the fully manured earths were filled throughout with young, vigorous roots, though, naturally enough, the roots were more abundant in the fertilized earth. In box No. II., which had been fertilized at the surface, there was a great preponderance of roots near the surface; while in No. III., which was fertilized below, the roots were below also, and it was hard to find any new roots in the upper layer of the soil. From these experiments, Nobbe concludes that the clover plant practically accommodates itself to circumstances, and that even in the third year of its life, — which was the year in which the roots were observed as above stated — clover takes most of its food from those layers of the soil where food is to be had most readily, no matter whether the layer be near the surface or deep down in the soil.

Stohmann also, having saturated a quantity of peat with dung liquor to which some superphosphate and potash salt had been added, rinsed away the excess of soluble matters, and spread the product layer by layer with crude peat in frames or boxes without bottoms, which were sunk in the earth.

No. I. had 9 inches of fertilized peat on top and 9 inches of crude peat below.
" II. had 9 inches of crude peat on top and 9 inches of fertilized peat below.
" III. had 6 inches of fertilized peat on top, then 6 inches of crude peat, and below that 6 inches of fertilized peat.
" IV. had 6 inches of crude, 4 inches of fertilized, and again 8 inches of crude peat.

Three grains of Indian corn were planted in each of the boxes. The young plants grew normally and vigorously from the very first, in boxes Nos. I. and III.; but in Nos. II. and IV. two of the seedlings soon died, and the surviving plants had a hard struggle until they reached the layer of fertilized earth, when they suddenly began to grow vigorously. The plant in No. IV. soon fell away, however, while that in No. II. prospered until it was ripe.

When the plants had ceased to grow, their roots were examined, and thick mats of fine tender roots were found wherever the fertilized peat had been reached. But in the layers of crude peat there was nothing but a few thick ligneous roots, which seemed to have died in all cases where they had not soon come into contact with a layer of the fertilized peat.

In box No. I. the whole surface layer of soil was filled with a mat of roots, while below the surface layer there was nothing but some remains of roots which had perished in trying to penetrate the layer of crude peat. In No. III. there was a thick mass of roots above, while below, especially at the sides of the box, there were a few individual roots which had reached the third layer, and had developed there so freely that the whole of the fertile earth was filled with a mat of them. In No. II. a few ligneous roots had reached the fertile soil and had developed there freely. In No. IV. also, a few strong roots had passed through the crude peat to the thin layer of fertile peat, and had completely filled it with fine fibres, but all the roots soon died on trying to penetrate the lower infertile layer.

Why some Plants grow on Special Soils.

The tendency of some plants to affect special kinds of soils is a fact to be mentioned in this connection, though it has comparatively little bearing upon the question of selective power in the sense above indicated. The truth seems to be, that, just as sea plants are adapted to the conditions in which they live, so strand plants and the plants of the alkali desert are adapted to the conditions and circumstances in which they are found. Familiar examples of this sort are seen in the use of salt on asparagus beds, whereby many weeds are killed, but not the asparagus plants. So, too, the cocoanut palm can resist sea-water surprisingly; and many plants are so constructed that they can support dry climates, and even live on arid deserts. Witness the pitch-pine trees (Pinus rigida) of the sand-hills of the Atlantic States.

It would be a very interesting study, for its own sake, to ascertain more clearly than has been done hitherto the laws which determine the localization of species upon special soils. Among other instances of such localization is the so-called "shoe-string," or lead-plant, which in the galena-bearing region of Missouri and Illinois has been thought to indicate the presence of lead ore.

With regard to non-corrosive soluble poisons, like barium chloride, for example, it is found, in consonance with the facts just now stated, that plants take in small quantities of these matters by way of osmose, and then die. On burning the plants thus killed, no large quantities of the poisonous matters are found within them, such as would assuredly have been sucked up in case the roots had been corroded and access had thus been opened to the capillary tubes in the plant.

Importance of the Chemical Matters excluded by Plants.

It is customary nowadays wholly to discard the old notion of Tull and of other intelligent farmers, that plants are capable of feeding directly upon the finer particles of soil. There is not, in fact, any evidence to support this view, though from the analogy of animal tissues it is perhaps not impossible that minute mobile cells, or even other minute solid particles, may pass, as such, from one part of a plant to another.

Of late years, attention has been directed more particularly to the power possessed by vegetation of decomposing the inert portions of soils by means of excluded chemicals, as was just now described. This fact is manifestly one of great importance, and worthy of far more careful and extended study than has been accorded to it hitherto. Enough knowledge has been gained already, however, to release chemists from the not wholly profitable discussion whether the soil-water, such as is found running from drains, contains enough matter in solution to feed the crops upon the land.

Much has been said, at one time or another, upon this point by different observers, for it is one involving so many obscure conditions that it is not by any means easy to arrive at definite conclusions with regard to it. The experiments of Dietrich, in particular, have shown that the consideration of this question may safely be dropped for the present.

Plants take Food from highly Dilute Solutions.

It is still true, however, that plants can derive food from exceedingly dilute solutions. Indeed, the experiments on water culture go

to show that dilute solutions are essential for the well-being of the plant. Nobbe, for example, found that the vigor of vegetation in his experiments diminished both when the proportion of solid matter in the solution was reduced below 0.5 part to 1,000 parts of water, or was increased to 2 parts in 1,000. In general, the proportion 1 to 1,000 may be remembered as one fit to be used under almost any circumstances.

The power of plants to extract food from exceedingly dilute solutions is shown very emphatically in the case of seaweeds. That is to say, of plants which live in the midst of water which holds dissolved only very minute traces of matters so important as phosphoric acid or even potash. The iodine also which sea plants contain must evidently be taken by them from the water in which they grow; but, as Otto has shown, there cannot be as much as one part of iodine in thirty million parts of the water.

The absorption of phosphoric acid by land plants is hardly less surprising, though in this case it cannot be positively asserted that the acid is always taken from solutions so dilute as the soil-water is. That it is sometimes taken from highly dilute solutions appears from the experiments of Birner and Lucanus on well-water as mentioned on a previous page. Ten million pounds of the water in question contained no more than 1½ lb. of phosphoric acid, and yet this water supported a crop that bore twice as much grain as was got from plants grown in an ordinary field for the sake of comparison.

In all such speculations as this, it is to be remembered that the contents of the soil-water may be continually renewed as fast as the plants remove them. The soil is not only a great storehouse, more or less filled with plant food, but it is likewise a workshop in which food is incessantly undergoing change and transformation.

It might be argued, for instance, that the good effects obtained by irrigating a mowing-field with brook-water are due solely to the fact that the grass plants absorb the almost infinitesimally minute proportion of phosphoric acid and other ingredients which the water has brought to the land; or it might be urged that the water, after having given up its original phosphoric acid, etc. to the grass, immediately acts upon the soil to dissolve out new quantities of plant-food and to carry them to the plants. In this way it might be possible for one and the same store of water to act over and over again upon the soil, and to carry much food from it to the crop.

But it may equally well be true, that the influence of matters dissolved in the original brook-water has been exerted indirectly to promote the growth of the grass. The chief part of the phosphoric acid, for example, found in the irrigated crop, may perhaps have come from the soil, whence it has been brought out by substances held dissolved in the water, or excluded by the plant, acting upon inert compounds in the soil.

Probably all these supposed methods of supplying plant-food may and do occur simultaneously, and it is to such complex considerations as these that must be referred the modes of action of many, if not of most manures. Hence the necessity of considering carefully what kinds of chemical action occur naturally in soils, before proceeding to discuss any one special kind of fertilizer, or trying to explain the causes of the benefits which are commonly obtained on applying it to the land for the use of crops.

CHAPTER VIII.

SOILS AS CHEMICAL AGENTS.

All kinds of soils, not even excepting drifting sands, possess much chemical activity. This fact may readily be illustrated by the simple experiment of digesting ammonia-water with clay, and searching for ammonia in the filtrate. Little or none of it will be found there. One way of trying the experiment would be to cut off the bottom of a large bottle, which could then be secured in a vertical position, mouth downward, and loosely plugged at the mouth by pushing down a tuft of cotton into the throat. On filling the body of the bottle loosely with clayey loam that has been slightly dampened, but not wet, and pouring small quantities of dilute ammonia-water upon the earth until liquid begins to drip from the mouth of the bottle, it will be found that this liquid is little more than mere water. By operating in this way, it has been proved that considerable quantities of ammonia may be retained by clay, and that ordinary agricultural soils do, in an analogous way, act chemically upon a great variety of compound substances.

The apparatus just described is well suited for studying the subject in detail. For example, if a number of inverted bottomless bottles were to be charged nearly full with sifted loam, and if there were to be poured upon the loam highly dilute solutions of various soluble salts, such as might occur in small quantity in any good soil, — such, for instance, as Epsom salt, Glauber's salt, and saltpetre, — it would be found, on examining the first portions of the filtrates, that they contained, respectively, not sulphate of magnesia, but the sulphates of soda, lime, and potash; not sulphate of soda, but the sulphates of magnesia, lime, and potash; not nitrate of potash, but the nitrates of lime, magnesia, and soda.

Bases are fixed and held by the Soil.

In each of the cases specified, the bases of the salts which were employed would be retained by the loam, i. e. by chemical agents which lurk in it, while lime, or some other base, would be removed from the loam, in combination with the sulphuric or the nitric acid of the salts that were contained in the original solutions.

If the experiment were to be varied by pouring a solution of phosphate of potash or silicate of potash upon the earth, it would be found that both the phosphoric and the silicic acids would be retained in the soil, as well as the base potash, because these particular acids form insoluble compounds by uniting with certain substances with which they come in contact in the earth.

One good way of trying experiments upon the fixing power of soils is to put a known weight of dry soil in a bottle together with a measured quantity of a solution of known strength of the substance to be examined, — sulphate of potash, for example; to shake the mixture at intervals for hours, or days, or weeks; and finally to subject to analysis a measured fraction of the clear liquid. The analysis will show, not only how much of the potash of the salt taken has been absorbed and "fixed" by that amount of earth, but what kinds and amounts of bases have been set free or pushed out from the soil by the potash which has taken their place.

As the result of many experiments, it has been proved that all good soils can and do decompose, to a certain point, the solutions of potash, soda, lime, and magnesia salts, in such wise that the metals or bases, together with phosphoric and silicic acids if they be present, are retained in the soil, while nitric, chlorhydric, and sulphuric acids remain dissolved in the form of compounds of lime or soda, or some other base or bases which they have taken from the soil.

It is to be observed that the absorption of one base is always attended by the liberation of an equivalent quantity of some other base or bases; and any base which has been absorbed may be set free again by the action of any other.

Of course, the capacity of any given soil to effect the decomposition is limited by the quantity of active chemical agents within it. If we persist in pouring either of the solutions upon the soil after it has become saturated with that special ingredient, the liquid will soon run through unchanged.

Although this fixing power is specially pronounced in loams, — i. e. in soils, properly so called, — it is still true that it may be exhibited distinctly enough in fragments of some kinds of rocks, notably in such as have been somewhat weathered superficially. Ullik has noticed fixation of potash and of phosphoric acid in pieces of compact basalt, and of certain marls and shales.

Fixation is seldom Complete.

For the sake of emphasis, the general fact of fixation has been stated above in terms so brief that the inference might perhaps be drawn that the whole of the potash is absorbed by the soil from the saltpetre, the whole of the magnesia from the Epsom salt, and so on. But no such inference would be correct, since in point of fact a certain small proportion of the potash, or other base, always escapes fixation.

Chemists are familiar with the fact, that in complex reactions, such as the foregoing must undoubtedly be, and in general whenever several compounds act upon one another in presence of water, the substances not infrequently decompose each other mutually in such wise that a certain part of the matter which would naturally, under simpler conditions, have become insoluble, does nevertheless remain dissolved in the water. It is not specially surprising, therefore, if some small part of almost any insoluble substance that is formed in presence of mixtures so complex as the soil and the soil-water are known to be should be found to remain dissolved in the water of the soil. Conversely, from the very fact that fixation is never quite complete, it is to be presumed that water can dissolve out from a soil a part of the potash or other base that has been fixed in it.

It is true, also, as a general rule, that the larger the number of bases that can be fixed in a soil, within certain limits, so much the stronger will be the power of that soil to fix other kinds of bases that may be brought to it.

Bases thus fixed by Loam are accessible to Crops.

The enormous importance of the foregoing facts will be perceived on reflecting that those portions of the soil-water which have been partially or wholly deprived of soluble matters by the action of the roots of plants can immediately obtain new supplies of plant-food by dissolving the substances which the soil has fixed. One and the same quantity of water might, in this sense, act over and over again upon the soil, and serve for a long time as a carrier of food from the soil to the plant. It is to be observed, however, that at the best the fixed matters are not readily soluble, and that the quantity of water needed in order to redissolve them is not only large, but much larger than the amount of water from which they were originally absorbed. That is to say, the power of the soil to hold the fixable matters is, on the whole, much greater than the power of water to dissolve them.

There is no difficulty, however, in conceiving of such continuous solvent action as that just indicated, if only the fact be held to that each of the several substances which the soil-water contains dissolved can diffuse into the root-cells quite independently of the water, and of every other substance.

What causes Fixation?

The seat of the fixing power, above described, is found to reside in certain hydrated double silicates of alumina (or iron), lime, and an alkali metal that are contained in the soil. The first intimation of this fact appeared from the researches of the English chemist Way, in 1850.

Way prepared artificially a double silicate of alumina and soda, by dissolving some silica and some alumina in separate portions of caustic soda, and then mixing the two solutions. The precipitated highly basic double silicate of alumina and soda was then washed with water and subjected to treatment with various saline solutions. By means of a salt of lime, Way found that he could remove almost the whole of the soda, and obtain a silicate of alumina and lime. By means of a potash salt he could remove the soda, and obtain a silicate of alumina and potash.

By means of magnesia salts, also, and of ammonia salts, double silicates containing these bases were obtained. But with the ammonia salt it was not possible to replace more than one third of the soda, or other soluble base, by ammonia.

Way's results were severely criticised by Liebig, — very unjustly,

as it then appeared to most chemists interested in the subject, and very unwisely, as it has since proved. The great merit of Way's research has been made only the more conspicuous in proportion as the subject has been more closely investigated.

Natural Double Silicates fix Bases as well as Artificial Silicates.

Instead of the artificial silicates of Way, several chemists, notably Eichhorn, and Mulder, have operated upon a number of natural hydrated silicates, such as occur in the minerals known as Zeolites.[1] It is found that these zeolitic minerals are decomposed more or less rapidly by solutions of salts of the alkalies (including salts of ammonia), and by those of the alkaline earths, and that lime is dissolved out from the zeolite, while the other base or bases are retained in its place. It appears that the bases of alkali metals are fixed in this way more readily than those of the alkaline earthy metals.

By reversing the experiment, and treating the factitious double silicate of alumina and soda, for example, or the changed zeolite, with the solution of a lime salt, the soda will be eliminated and lime fixed again; — and so with the other bases, any of them may be made to replace the others if time enough be allowed for the liquids to act.

The Fixation of Bases is Speedy.

Generally speaking, the process of absorption and fixation of bases by the soil is rather rapid. Way found that the fixation of ammonia was often completed in half an hour, and Mulder has stated that one hour was sufficient for the fixation of bases in his experiments; though Peters observed that for the saturation of a soil with potash 48 hours were required.

Henneberg and Stohmann noticed that phosphoric acid continued to be fixed after the lapse of 24 hours, and several observers have urged that phosphoric acid is often fixed rather slowly. Indeed, Voelcker has found in some instances that the process was not entirely completed at the end of three weeks. But it is hardly proper to discuss the fixation of phosphoric acid in this particular place, since it is known to depend upon different reactions from those which control the fixation of bases such as potash and ammonia.

It has been observed that the bases are absorbed more rapidly from solutions of some of their salts than from others. Potash, for example, is absorbed in least proportion from solutions of chloride of potassium, and in largest proportion from solutions of the phos-

[1] Described in "How Crops Feed," p. 114.

phate, hydrate, and carbonate. Moreover, the bases are absorbed by the soil from strong solutions more rapidly and more completely than they are from dilute solutions.

Soils vary as to their Fixing Power.

Naturally enough, soils vary widely as to their absorptive power. Thus Rautenberg found that different kinds of soils tested by him absorbed quantities of ammonia ranging from 7 parts to 25. Variations such as these are readily explained, by assuming that more or less of the active double silicates are contained in one soil than in another, and it is found in fact that, if a soil be thoroughly washed with acids to remove the bases which it holds or has absorbed, its fixing power will be greatly diminished, manifestly through the destruction of the effective silicates which were contained in it. By adding a quantity of the zeolitic mineral to an ordinary soil, it is found that the power of the soil to absorb and fix bases is increased.

Are there Zeolites in ordinary Soils?

It is hard to prove that there are really zeolites in the soil, but it has been found that the fixing power of a soil is closely connected with the quantity of alumina and iron which the soil yields to diluted chlorhydric acid, as well as with the amount of silica set free from the soil by the action of such acid. Both these items of evidence go to show the probability of the soil's containing zeolites, for these minerals would act in this way with acids if they were there.

To estimate the amount of this zeolitic or so-called soluble silica, it is necessary to leach the soil with a hot solution of carbonate of soda, both before and after the treatment with the diluted acid. Heiden has in this way determined the amount of soluble silica, such as occurs in zeolites, that is contained in various soils, and he finds from 2 to 7%, or more. He urges that considerable quantities of the zeolitic silica are really present in ordinary loams, and that it must be regarded as a normal constituent of loams. It is to be presumed that it is with the alumina and iron of these hydrated silicates that phosphoric acid unites when it is finally fixed in the earth, no matter whether it may have been applied as farmyard manure, as superphosphate, or in the form of some other variety of phosphate of lime.

In connection with his experiments on natural zeolitic minerals, Mulder prepared artificially a substance of analogous composition,

by dissolving hydraulic cement in muriatic acid, and adding to the solution enough ammonia-water to neutralize the acid. The gelatinous precipitate thus formed, after having been washed with water, was found to contain a certain quantity of a double silicate of alumina, iron, and lime, beside hydrate of iron, alumina, and free silicic acid. On drenching this precipitate with dilute saline solutions of one kind or another, in order to test its fixing power, it was found that, like the artificial silicates of Way, this substance was competent to fix potash, magnesia, ammonia, and soda, while lime went into solution and was removed. Mulder proved also that silicates which contain ferric oxide (Fe_2O_3) instead of alumina (Al_2O_3) can serve to fix bases of the alkali metals and the alkaline earths.

In general, hydrated double silicates exhibit much more fixing power than silicates from which the water of hydration has been expelled. Way showed in his original research, that by burning or calcining a soil its absorptive power is diminished, or even destroyed; and by exposing his artificial precipitated silicates to strong heat, he destroyed their ability to react upon saline solutions so as to fix or absorb their bases. But it is now recognized that, although the absorptive power of soils is greatly diminished by calcining them, it is not necessarily wholly destroyed by the calcination.

Even coal ashes have a certain small absorptive power, and Eichhorn has shown that some anhydrous mineral silicates are acted upon by saline solutions, though slowly, and that the bases of the salts are absorbed. In one case recorded by Peters, 0.1841 grm. of potash was absorbed by a natural loam from a solution of potassium chloride, while 0.12 grm. was absorbed by the same loam after it had been burned to ashes.

Incessant Chemical Action in Soils.

It is evident enough from the foregoing, that important changes, and changes almost infinite in variety, must be continually occurring in the soil by virtue of reactions in which the double silicates take part. With the exception perhaps of midwinter, when everything is frozen stiff, it is certain that chemical changes are constantly occurring in every soil. From the chemical point of view, nothing like rest can be conceived of in a mixture so complex as the loam of an ordinary field.

On the contrary, it is known that the constituents of such earth are subjected to incessant action, counter action, and change. If

crops are growing on the land there will be many special changes, due to the activities of the plant roots, that would not occur if the field were lying fallow; but although the changes which the soil undergoes will be different in the two cases, there is small reason to believe that there will be any fewer of them in the one case than in the other.

With regard to the fixation of bases by zeolites, it is important to observe, that, although the compounds formed by such fixation give up a part of their alkali to pure water, and are consequently capable of feeding plants directly, the fixed matters must be still more readily soluble in carbonic-acid water, and in the acids exuded or excluded by the roots of plants. It may here be said that neither quartz-sand, nor kaolin, nor chalk, nor humus from decayed wood, nor the hydrates of iron or alumina — no matter whether they be taken singly or admixed — have any power to decompose salts and fix their bases in the manner just described. No more has lime, magnesia, alumina, phosphate of alumina, or gelatinous silica.

As will be shown in another place, certain double humates of lime, or what not, have the power of fixing potash, ammonia, &c. in the soil in a manner analogous to that exhibited by the double silicates. Special stress is commonly laid by teachers upon the action of the silicates, because, taking the world through, the efficient silicates are much more abundant than the humates.

Physical Fixation, as distinguished from Chemical.

Beside the chemical absorptive power due to the action of double silicates or double humates, as above set forth, soils have another, apparently purely physical power of absorbing coloring matters, gases, and even saline matters, by mere force of adhesion or surface attraction, just as charcoal has.

In some kinds of peaty soils, indeed, it is found that this physical power of fixation is distinctly larger than the chemical power; though as a general rule by far the larger part of the matters fixed by soils are fixed by chemical means.

Examples of physical absorption by soils were noticed much earlier than those which depend upon chemical action. Naturally enough, practical men have long observed how readily barnyard liquor and other colored waters are made clear and odorless when put in contact with fresh loam or clay. Several writers at one time or another have called attention to the fact, and have dwelt upon its importance, — notably Gazzeri in 1819, Bronner in 1836,

Huxtable in 1848, and Way in 1850. Manifestly this fixation of coloring matters, etc. by the soil is closely analogous to the fixing of such things by charcoal and by vegetable tissues. There is an adage current in New England, that clothes upon which the fetor of the skunk has fallen may be "sweetened" by burying them in earth. The Indians are said to purify the carcass even of the skunk in this way, so as to fit it to be eaten; and in like manner the bones buried by dogs remain comparatively free from offensive odor.

Other applications of the same principle are seen in the "earth closet" system of deodorizing human excrements, and sometimes in the use of loam and peat upon manure heaps, both of which points will need to be discussed in another chapter. Not only are coloring matters and gases, i. e. fetid exhalations, thus absorbed by the soil, but many soluble chemical substances also.

It is an instructive experiment to put a quantity of half-dried garden loam in a bottle together with some liquor that has drained from a dung-heap, to shake the two together, and finally to filter the mixture. If a proper proportion has been maintained between the amounts of loam and of liquid, the filtrate will be found to be mere water, almost completely colorless, devoid of odor, and well-nigh tasteless. This experiment is going on incessantly in nature. Drinking water as it flows from springs or is drawn from wells is a filtrate not much unlike that of the experiment. The experiment itself is similar in kind to the process employed in sugar refineries, where the brown color of raw sugar is removed by filtering solutions of it through bone-black. The coloring matter adheres to the innumerable surfaces of the particles of bone-black in the one case, and to those of the porous soil in the other, and is thus held fast.

Saline Matters fixed by Adhesion.

As was just now said, it is well known that, besides coloring matters, small quantities of soluble saline substances can adhere to the soil. Even in the use of bone charcoal for purifying syrup, some sugar adheres to the coal; and when other crystalline chemicals are purified by means of this agent, it usually happens that some portion of them is lost through adhesion to the coal.

Numerous observations of facts of this character even as regards soils are upon record, and a considerable number of them have been collected and published by Way.

Thus Lord Bacon remembers "to have somewhere read that trial hath been made of salt-water passed through earth through ten

vessels one within another, and yet it hath not lost its saltness as to become potable; but when drayned through twenty vessels, hath become fresh."

Hales, in 1739, mentions, on the authority of Boyle Godfrey, that "sea-water, being filtered through stone cisterns, the first pint that runs through will be pure water having no taste of salt, but the next pint will be salt as usual." Some allowance must be made in crude experiments such as these for the fresh water originally held in the pores of the stones, which would be pushed out by the salt water in such wise that the first drops of the filtrate would be fresh.

Berzelius found, on filtering solutions of common salt through sand, that the first portions of the filtrate were free from salt, and Matteucci observed the same thing as regards other salts besides chloride of sodium.

Another Italian chemist, Gazzeri, wrote as follows in 1819: "Loam and especially clay take possession of soluble matters which are intrusted to the soil, and retain them in order to give them by degrees to plants, conformably with their needs." And the German horticulturist Bronner, in 1836, in speaking of the clarifying of dung liquor by earth, insisted that even the soluble salts in the dung liquor are absorbed by the earth, and held so strongly by it that they are only washed out to a small extent by new quantities of water.

Wagemann found, on filtering acetic acid and diluted alcohol through pure sand, that the first portions of the filtrates were almost pure water.

As recently as 1878, Roberts has maintained that a sandstone at Liverpool, through which sea-water slowly percolates, exerts an appreciable influence to hold back the salt. To test the matter, he prepared cubes of the sandstone, 12 inches square, dished out on top so as to hold water, and varnished on the sides to prevent leakage. He dried these cubes thoroughly in the air, placed them one above another in a frame, and poured sea-water upon the top of the uppermost. Matters were so arranged that the water which passed through the upper cube should drop into the cup at the top of the lower one, while that which dropped from the bottom of the lower cube was received in a bottle, for analysis.

Clear water from the river Mersey was added by small portions to the dish of the upper cube until drops began to fall from the bottom of the stone, and when two fluid ounces of liquid had passed through, the amount of chlorides contained in it was determined.

It appeared on this first trial that almost 81% of the chlorides of the original sea-water had been removed by the sandstone.

Water was then allowed to filter through the first cube and to drop upon the second, until it passed without any change from the original condition of the sea-water. The second cube was thus partially saturated with the filtrate from the first cube, and sea-water was added continuously till it began to drop from the bottom of the second cube, where it was collected and analyzed. The results of these trials are given in the following table.

Filtrates from 2 c. ft. of Sandstone.	Quantity of Liquid, in Fluid oz.	Percentage of Chlorides removed.
1st filtrate	3½	80.8
2d "	4	76.6
3d "	4	71.3
4th "	4	64.9
5th "	4	57.4
6th "	4	53.2
7th "	4	46.8
8th "	8	44.7
9th "	8	31.9
10th "	8	25.5
11th "	8	21.3
12th "	8	10.6
13th "	8	10.6
14th "	18	8.5

The last drops of the 14th filtrate had the same composition as the sea-water showing that the absorptive power of the stones was exhausted. It appeared that 93½ fluid ounces of the sea-water passed through the two cubic feet of sandstone before they became inoperative as filters, and that nearly the whole of the salts were removed from the water that first passed through.

In order to determine whether this fixation of chlorides was a mechanical or a chemical process, Roberts allowed one of the cubes of stone which had become saturated as above to dry in the air for a month, and then poured spring-water into the dished part; as he had done before with the sea-water. The results obtained in this way are given in the table.

Filtrates from 1 c. ft. of Sandstone.	Quantity of Liquid in Fluid oz.	Percentage of Chlorides washed out.	
1st filtrate	24	157.77	in 101 fluid oz.
2d "	45	122.22	
3d "	32	102.22	
4th "	40	55.55	in 92 fluid oz.
5th "	40	4.44	
6th "	12	2.22	

Taking sea-water at 100 as the standard for comparison, it appeared that in the 1st filtrate of 24 fluid ounces there was an increase of 57.77 of the chlorides; and the 3d filtrate shows that it required 101 fluid ounces of water to reduce the salts that had accumulated in the pores of the sandstone during the previous filtration of the sea-water to the standard of the original sea-water. The 6th filtrate shows that the 92 additional fluid ounces of spring-water washed out all the remaining chlorides. The last drops of the 6th filtrate showed only a trace of salts remaining. It appears, therefore, that the fixation of salt by the sandstone was purely mechanical, and not dependent upon any chemical action of the sandstone upon sea-water.

As regards charcoal, it should be said that its power of retaining salts, as well as coloring matters, has long been familiar to apothecaries and the manufacturers of fine chemicals.

It is evident enough that in some of the examples in the foregoing list phenomena of physical fixation were supplemented to a greater or less extent by those of chemical absorption. Practically, the two kinds of absorption must constantly act together, i. e. simultaneously and side by side, in the same soil. But it is important that the two conceptions should be held apart, and that we should try to distinguish between cases where one or the other of the two kinds of absorption would be likely to have a preponderating influence. Generally speaking, chemical absorption is far more important than physical. In other words, there are good reasons for believing that much of the potash, lime, magnesia, ammonia, and soda which plants take from the soil existed there either in the form of the hydrated double silicates or of the double humates above described; and it is known, also, that small quantities of saline matters, such as plants need, may be held in the soil by force of mere adhesion.

The whole subject of the fixing power of soils has been well treated by Professor Johnson, in "How Crops Feed," p. 333. The student will there find judicious selections from the details of numerous experiments.

It may be well to remark yet again, that, while the power of sand to retain salts by adhesion has doubtless some slight influence in preventing the admixture of sea-water with the ground-water of land near the sea, it is in no sense the prime cause of the freshness of water in wells dug in sand near the shore, as has been already

explained. Manifestly the physical absorptive power of a soil will be greater in proportion as the soil is porous, and the power of sand must always be comparatively feeble on this account, since the particles of sand are solid and destitute of pores.

CHAPTER IX.

MODES OF ACTION OF SPECIAL MANURES.

In passing to the consideration of different kinds of manures, and the theory of the action of each special kind, it is a matter of much indifference which particular fertilizers are first chosen as subjects for study. It is necessary only that care should be taken to discuss some of the simpler instances at the beginning, and to proceed step by step to cases which are more complex. It needs to be insisted, however, at the start, that the word "simple" is here used merely as a term of comparison, for it is wellnigh impossible to conceive of simplicity of action on the part of any substance put in contact with a mixture so complex and variable as the soil is.

In point of fact, there is no manure so simple in its action that this action can be comprehended at a glance.

Gypsum, or Plaster of Paris.

As an example, gypsum may be taken, otherwise called "plaster," or plaster of Paris, or sulphate of lime. This substance has been used as a fertilizer from time immemorial. Even the Greeks and Romans employed it in this sense. According to several French agricultural writers, considerable quantities of gypsum were exported from France to America during the last century, to be used for fertilizing purposes. At the present time, large quantities of it are brought to New England from Nova Scotia, and the material is abundant in some parts of the State of New York.

There is a story that Benjamin Franklin in his time strewed gypsum upon a clover field, so that the words, "This has been plastered," were written in gypsum upon the middle of the field, and could be read there as long as the crop remained upon the land; i. e. the plastered clover grew more vigorously than the rest of the crop.

It was thought at one time, that the good effects of gypsum on clover are due solely to the lime in the gypsum, and even so acute an observer as Boussingault defended this proposition. He found in fact that clover, to which he applied gypsum for two years in succession, contained much more lime than similar clover which had not been treated with gypsum. But more recent observations have shown that Boussingault's results were in some sort exceptional, and that the application of gypsum to clover does not necessarily surcharge the plant with lime. Moreover, if clover were "a lime plant," as has often been held, and if it were true that it habitually takes much lime from gypsum, the question would still be left to answer, Why should gypsum be a better fertilizer for clover than lime itself, or than any other compound of lime?

Another old idea was, that gypsum absorbs and fixes ammonia from the air, as will be explained directly. But these hypotheses failed wholly to clear up the well-known fact, that the action of gypsum as a fertilizer is exceedingly capricious, and that its behavior upon any untried soil could seldom be predicated with any certainty. Many years ago Stoeckhardt wrote as follows: "The action of gypsum, perhaps more than that of any other manure, depends upon the kind of soil and crop, upon climate and other conditions, and is subject to manifold limitations." And yet, with the progress of knowledge, gypsum has now become a fit subject for an initial chapter on fertilizers because of the simplicity of its action.

Gypsum forces Potash from the Soil.

The fact is, that the experiments of several different observers, working independently of one another, have shown that gypsum exerts a powerful action in setting free potash which has been absorbed and fixed by the earth, that is to say, by double silicates in the earth.

It is found that the lime of the gypsum is fixed in the soil, while a corresponding quantity of sulphate of potash goes into solution.

$$\left.\begin{matrix} Al_2O_3 \\ CaO \\ K_2O \\ H_2O \end{matrix}\right\} x\,SiO_2 + CaO,SO_3 = \left.\begin{matrix} Al_2O_3 \\ CaO \\ CaO \\ H_2O \end{matrix}\right\} x\,SiO_2 + K_2O,SO_3$$

Thus it happens not only that gypsum sets free potash (as well as magnesia and ammonia) for the use of the crop, but it causes potash to be transferred from the upper to the lower layers of the

soil, so that the roots can everywhere find a store of it. This last-mentioned point is one of no little importance in the case of deep-rooted plants, such as clover and the other Leguminosæ.

There is no lack of evidence to show that gypsum really does act in the manner above stated. For example, Boussingault, many years ago, strewed gypsum on one part of a clover field, and analyzed the ashes of the plants there gathered, as contrasted with the ashes of clover plants from a contiguous part of the field that had received no gypsum.

It will be seen from the following statement of the analyses, that very much more potash, and magnesia also, were taken up by the plants that had been dressed with gypsum than by the others. It might be argued, indeed, and with justice, that the more vigorous plants of the gypsum patch were able to take up more food than the others. But there will still remain abundant ground for the conviction that the gypsum must have acted upon the soil to loosen up its constituents.

Boussingault himself, having no inkling of the absorptive power of soils, which was not discovered until some years after his experiments, was particularly impressed by the large amount of lime in the ashes of the gypsum plants; but in the light of the wider experience of to-day, it is plain that the great preponderance of potash is the more important consideration. In the clover from a hectare were found the following quantities, in kilos, of the several ash ingredients:—

	1st year, 1841.		2d year, 1842.	
	Gypsum.	No Gypsum.	Gypsum.	No Gypsum.
Ashes, free from CO_2	270.0	113.0	280.0	97.0
Silica	28.1	22.7	104.0	12.7
Oxides of Iron, Manganese, and Alumina	2.7	1.4	?	0.6
Lime	79.4	32.2	102.8	32.2
Magnesia	18.1	8.6	28.5	7.1
Potash	95.6	26.7	97.2	28.6
Soda	2.4	1.4	0.8	2.8
Sulphuric Acid	9.2	4.4	9.0	3.0
Phosphoric Acid	24.2	11.0	22.9	7.0
Chlorine	10.3	4.6	8.4	3.0

One important bit of evidence is seen in the fact that sulphate of magnesia acts very much in the same way that gypsum does, both empirically as a fertilizer and in the laboratory, when used as a means of setting potash free from the hydrous silicates. Pincus

harvested the following quantities of hay per Morgen (= 0.631 acre) from land treated as stated.

Meadow not manured	21.6 cwt.
Meadow treated with gypsum	30.6 "
Meadow treated with sulphate of magnesia . . .	32.4 "

And numerous trials of leaching loams, in great variety, with a solution of gypsum, have shown that much more potash, magnesia, and soda can be extracted by this solvent than by mere water. Meanwhile, it is observed that a part of the lime of the gypsum is absorbed and fixed by the loams.

In Germany, where enormous quantities of gypsum were formerly used upon red clover, it was thought at one time that the best season for applying the fertilizer is in the spring, when the plants are 3 or 4 inches high, and the earth is completely covered with the young leaves. And from the fact that gypsum acts with special vigor upon clover when strewn upon it in this way, it was supposed by some observers that the clover absorbs the gypsum through its leaves as fast as it is dissolved by dew or rain. This idea is probably erroneous. But it is evident that the gypsum thus strewn upon clover leaves is peculiarly well placed to enable it to act upon the soil about the roots of the plants.

When dissolved by rain and heavy dew, the gypsum, or rather its solution, would flow down the stems of the plants, and be absorbed by the soil immediately around them. The plan of thus spreading gypsum on the leaves was combated long ago by De Marras, who urged that the best time to strew gypsum is in the autumn, rather than after the crop has started, or than in the early spring even. This opinion appears to be now quite generally held, viz. that gypsum should be applied to the land some months before the crop for whose benefit it is used, in order that there may be time enough for it to act upon the matters in the soil.

Admitting that the chief value of gypsum depends on its power of setting free potash, it is plain that some little time will often be needed for the accomplishment of this purpose. There is no longer any difficulty, moreover, in explaining how it is that gypsum sometimes does its best service on fairly good soils, which have been well manured and kept in good heart, so that potash may have accumulated in them. Nor is there any difficulty in seeing why gypsum is apparently so capricious in its action; for upon soils

that are tolerably rich in fixed potash it will do good service, while upon soils poor in potash it will not.

Gypsum has in fact often been found useful on new lands of certain kinds and qualities, and on old fields which have been cropped and fertilized in a way which was perhaps not wholly judicious. It is often of great use in regions where wheat is grown in alternation with clover, since by encouraging the growth of the clover it acts as a manure for the wheat.

But it is none the less true, that gypsum is a fit manure neither for poor land nor for regions where high farming is practised. It has found place only in districts where the methods of farming were simple, and so to say backward, and is really a fertilizer of times that are past. The action of gypsum is too slow and too feeble to meet the requirements of modern agriculture, at least on farms where the soil is highly manured, and where complex systems of cropping are practised. Wherever there is profit to be got from high farming, gypsum would usually be found to be a much less efficient fertilizer than potassic manures, used either as such, or in conjunction with lime or with leached ashes.

In any event, gypsum is to be regarded as an excitant, rather than as a form of plant food. That is to say, it is a manure of indirect action. An illustration of this fact may be seen in the following experiment of Heinrich. Gypsum was applied, in contrast with sulphate of potash, upon mixed clover and timothy grass on a poor, sandy soil, that had never previously borne clover within the memory of man. There was obtained per Morgen (= 0.631 acre) 1,400 lb. of dry crop from the unmanured land, 1,653 lb. from the gypsum plot, and 1,772 lb. from the plot dressed with sulphate of potash; and it was noticed that the growth of clover, rather than that of the true grass, was favored by the gypsum.

Of course, gypsum can, and does, supply plants with lime and sulphur in cases where the plants need more of these things than can be found already in the soil; but, considered as a manure of direct action, it has infinitely less significance than bone-meal, guano, superphosphate of lime, and the like, which actually give to the plant substances which are lacking in the soil.

Gypsum is said to be more highly esteemed in moist than in dry climates, though it is taught that the soil on which it may be placed should be neither heavy nor wet. It is thought to be good practice to strew gypsum at a moist time; and it is plain, in any event,

that the soil should be moist enough to permit and facilitate the action of the sulphate upon the potassic silicate. Moreover, the physical condition of the soil can hardly fail of having considerable influence upon this reaction, for the decomposing action of the sulphate will be more or less rapid and complete, not only according as the soil is wet or dry, but according as it is light or heavy, mellow or stiff. In soils not properly aerated that are rich in organic matter, the sulphate will be reduced to calcium sulphide (CaS).

Gypsum favors Clover.

As was said before, gypsum seems to be best fitted for use upon leafy crops, particularly upon clover and the other kinds of leguminous plants. Indeed, it came long ago to be regarded in some sort as a special manure for clover, just as potash compounds are nowadays, as will be shown on another page. It is a matter of common observation, that the application of gypsum to pastures and mowing-fields favors the growth of white clover.

With regard to the notion that clover is a lime plant, and that sulphate of lime is good for it on this account, Knop has remarked, that it is in one sense hardly fair to regard clover as a plant specially grateful for lime. It is a matter of observation, that all leaves contain a comparatively large proportion of lime; and, as clover is a leafy plant, a good deal of lime is taken from the soil by a crop of it. But it does not therefore follow that the need of the entire plant is especially lime.

In other words, if there be applied to the clover plant all the nitrogen, potash, and phosphoric acid it can dispose of, the chances are, that, as soils go, it can usually get out of the earth all the lime it will need.

It is noteworthy that the chemical efficacy of gypsum depends as much upon the sulphuric acid contained in it as upon the lime. It is sulphate of potash that goes into solution when the gypsum acts upon the soil. It is sulphate of ammonia that is formed when moist gypsum acts upon carbonate of ammonia in manure or in the soil, or when gypsum acts upon humus or other porous component of the soil which has charged itself with ammonia by absorption. So too some of the sulphur in the gypsum is consumed as plant-food, as well as the lime.

Action of Gypsum on Ammonium Carbonate.

So many statements are to be found in old works on agricultural chemistry relating to the power of gypsum to absorb and retain

ammonia from the air, that this point deserves to be mentioned, although it can no longer be considered as of importance. It is now known that in ordinary air there is next to no ammonia to be absorbed. In horse stables and sheep stalls, it is true, the use of gypsum in this sense may sometimes be appropriate. But it is to be remembered, that the gypsum must be moist in order that the desired reaction shall occur.

$$CaSO_4 + (NH_4)_2CO_3 = CaCO_3 + (NH_4)_2SO_4.$$

In case dry powdered gypsum and solid ammonium carbonate be stirred together, the odor of the ammonium salt will continue to be perceived. But if water be poured upon the mixture, the odor will cease; and on filtering the moist mass there will be found in the filtrate, not carbonate of ammonia, but the non-volatile sulphate of that base, while insoluble carbonate of lime remains on the filter. It is evident, therefore, that gypsum must be moist if it is to be of use as an absorbent of ammonia in the soil or upon a dung-heap.

Gypsum may often do good upon some kinds of soils, in that, like other calcium compounds, it can act to improve their mechanical condition by causing the finer particles to flocculate or granulate, as will be explained under the heads of Lime and Common Salt. But for this particular purpose lime would usually be a better material to apply to the land than gypsum.

Gypsum may preserve Dung.

Several observers have noticed that, when gypsum is mixed with decaying organic matters, it acts as a preservative, and that the loss of nitrogen from the materials, as free nitrogen gas, is lessened. Morren has observed, moreover, in experiments where 5% of gypsum was added to blood, bone-meal, and horn-meal, that the decaying matters remained slightly acid and lost considerably less of their nitrogen than when they were allowed to ferment either by themselves or admixed with earth. In the absence of gypsum, the materials became alkaline and evidently fermented in a different way. Koenig and Kiesow, on the contrary, who stirred up bone-meal or flesh with gypsum and water to a pap, and allowed the materials to ferment, found that they became alkaline, and that, while considerable quantities of ammonia were formed and retained, the gypsum wholly prevented a loss of nitrogen.

Wolff packed cow manure together with 200 grams of gypsum in a box of one cubic foot capacity. The mixture, which weighed 12,723 grams at first, was left for 15 months in a north room, in

contrast with several similar boxes that contained either simple cow manure or mixtures of manure and other preservatives. The loss of weight from the plastered manure was slightly less than that from the mere manure, and a larger quantity of organic matter remained undecomposed in the plastered box; but it was noticed that the rotted manure contained a decidedly smaller proportion of soluble organic matters, and a larger proportion of insoluble nitrogen compounds in cases where gypsum had been used, than where none of it was present.

The inference was that the gypsum speedily combined with certain soluble organic matters in the manure, and made them insoluble, and so tended to preserve the manure and the nitrogen in it, or, at the least, to hinder decay. As Wolff remarks, some of the matters thus fixed by the gypsum are precisely those which would naturally ferment and decay most readily if left to themselves.

Heiden finds that waste phosphatic gypsum (see beyond) from superphosphate works is even more effective than ordinary gypsum for preserving manure. He strewed the phosphatic gypsum, morning, noon, and night, on the dung and in the troughs of a cow stable at the rate of 2.2 lb. per diem for every 1,100 lb. live weight of the animals. From July to October, inclusive, there was produced 27,500 lb. of manure containing 5,650 lb. of dry matter, and after 15 weeks there was still found in the dung-heap 24,250 lb. of this manure and 4,675 lb. of dry matter. The loss of moist manure was 12% and the loss of dry matter 17.2%; while in a similar trial with manure to which no gypsum was added, but which had been carefully kept in compact heaps, the loss from the moist manure was 20½% and from the dry matter 36%. When ordinary land plaster was used, the heap of fresh manure lost 6.7% of its weight in 15 weeks, and 21½% of its dry matter.

During the 15 weeks 22% of the original nitrogen was lost from the plain manure, while only 6% of that in the manure treated with the phosphatic gypsum disappeared. In other words, the phosphatic gypsum reduced the loss of dry matter one half, and that of the nitrogen nearly four times. It was noticed that the temperature of the plastered dung-heap remained comparatively low, and this fact might of itself explain the small amount of decomposition.

In dung liquor that had been mixed with the phosphatic gypsum the loss of nitrogen was 12⅓%, while from mere dung liquor 66 and 70% of the nitrogen went to waste. It was manifest that the gyp-

sum acted both to fix ammonia and to prevent decay of nitrogenous organic matters.

Troschke, on the other hand, noticed very considerable losses both of dry matter and of nitrogen in manure that was kept three months after having been treated with gypsum or with kainit. In the case of gypsum the loss amounted to 19% of the dry matter and 32% of the nitrogen; while with kainit the loss of dry matter was 20% and that of nitrogen 10%. A strong odor of sulphuretted hydrogen was given off from the heap that contained the gypsum.

It would seem indeed that the use of gypsum for preserving manure must be subject to various limitations. The experience of practical men with regard to it points also to this conclusion, for in some instances it has served them an excellent purpose, while in others it has failed to justify itself.

Christiani published years ago the results of experiments in which potatoes dressed with plastered manure gave a much better crop than was got from the same amount of manure which had not been treated with gypsum, and similar results have been reported by Eichhorn, Didieur, and other observers. But no very encouraging results were reached in trials that were made in Prussia some years since, by different persons, to test the practical utility of strewing gypsum on fresh cow manure at the rate of 2 to 2½ lb. of land-plaster to 100 lb. of the fresh dung.

It did not appear to the people who tried these experiments that there was any particular use in employing the gypsum in this way. For although it was noticed in several instances that the gypsum seemed to delay the fermentation of the dung, it was thought and argued that the farmer has already other methods of accomplishing this result which are cheaper than the use of gypsum.

Strewing of Gypsum in Stables.

But though possibly not to be recommended as a direct addition to the manure heap, it is none the less true that gypsum scattered on moist places in horse stables and cow stalls may do excellent service by checking the fermentation of the urine, and by absorbing some of the odors which arise from it. For this purpose it has been extensively used in many localities. Heiden has found, by direct experiment, that, on mixing 2 or 3% of gypsum with stable manure that contained ammonium carbonate, much of the latter was arrested. (Compare Kainit, under Potash Compounds.)

Some Soils and Waters contain Gypsum.

It is to be observed that many soils as in Boston and its immediate vicinity naturally contain more or less gypsum. This natural gypsum is derived from several sources. Many rocks contain iron pyrites, and where this mineral comes in contact with air it changes to soluble sulphate of iron, and the latter is in its turn decomposed by lime salts in the soil, with formation of gypsum.

All those ingredients of plants and animals which contain sulphur give rise to the formation of sulphuric acid as they rot in the soil, or they form gaseous sulphuretted hydrogen, which is subsequently oxidized in the air to sulphuric acid, and the acid thus formed is carried down by rain to form sulphate of lime in the soil. So too with the sulphurous acid which results from the burning of coal. Thus it is that the yearly waste of the sulphate which goes to sea in the waters of brooks and rivers is made good.

The "hard" water of very many wells in the vicinity of Boston owes its hardness to the fact that a large proportion of sulphate of lime is held dissolved in it. The "scale" which forms in steam-boilers and "water-backs" fed with such water is sulphate of lime, just as the scale of marine boilers is.

Besides the quarries of gypsum from which the chief supply of this fertilizer is drawn, there are several subordinate sources which are worth mentioning. When sea-water or the water of saline springs is evaporated to obtain common salt, considerable quantities of gypsum are deposited. Sometimes this deposit is raked from the vats and thrown away, and at other times it is sold as a manure. In the manufacture of soda-water and some other effervescing drinks, powdered marble is treated with sulphuric acid to set free carbonic acid gas, but the residue is acidified gypsum, and it may be had of the apothecaries or makers of soda-water for the asking. So too, the refuse of the workers in stucco and plaster of Paris, and of stereotypers, dentists, and other persons who make plaster casts.

In the aggregate, a very large quantity of this material is thrown away daily in a city like Boston. All stucco-work and the cornices around the interiors of rooms contain more or less plaster of Paris, and so does the mixture with which masons repair cracks in ordinary plastering.

The spent lime of gas-works contains much gypsum, especially after the material has been allowed to weather; and so do the ashes

of some kinds of peat and some kinds of bituminous coal, as well as wood ashes, and even anthracite ashes to a certain extent.

In Germany of late years large quantities of gypsum that contains traces of phosphate of lime have been as good as given away by the manufacturers of high grade superphosphate of lime, in the preparation of which substance the gypsum is formed incidentally, as a waste product. In the Rhine region this waste gypsum is held to be worth no more than 25 cents the long ton, as it lies in heaps at the works, and less than twice this price when put upon railway cars at the cost of the manufacturer.

Gypsum as an Oxidizing Agent.

There is yet another mode of action of gypsum which may properly be mentioned here, though there will be occasion to refer to it more particularly hereafter, viz. its oxidizing power. Sulphate of lime, $CaSO_4$, is a substance that contains a considerable amount of oxygen (almost half its weight), and it gives up this oxygen rather easily to many other substances. Hence it is by no means impossible that part of the good effect of gypsum, when employed as a fertilizer, may be due to this oxidizing power brought to bear upon nitrogenous and carbonaceous substances in the soil.

Gypsum is commonly used at the rate of 200 or 300 lb. to the acre, — about as much as a man can conveniently scatter from his hand in walking across the field.

CHAPTER X.

PHOSPHATIC FERTILIZERS.

Phosphate of lime, a substance which has acquired great commercial importance in recent years, is a fertilizer of a very different order from gypsum, and one of much greater consequence. There are several varieties of this substance, for the term "phosphate of lime" includes such well-known fertilizers as bone-meal, bone-ash, bone-black, superphosphate of lime, phosphate rock, such as is found in South Carolina, North Carolina, Alabama, Canada, and in many foreign localities, and the phosphatic guanos, such as those of Baker's Island, Jarvis Island, and Howland's Island in the Pa-

cific, and Navassa, Sombrero, Aves, and the other guano islands of the West Indies.

Bones.

It will be well first of all to consider bones, both as to their mechanical and their chemical composition. If a bone is soaked for some time in dilute muriatic acid, there will be left a tough elastic mass of organic matter, of the same shape as the original bone. On the other hand, if a bone be burned thoroughly in the fire, there will be left a friable earthy substance, known as bone-ash, which, though free from any trace of the elastic matter, may also exhibit the original shape of the bone.

By the process of burning, all the carbonaceous or other "organic" portions of the bone have been converted into gaseous products, which disappear in the air; while by the action of the acid, in the previous experiment, the earthy portion of the bone simply went into solution. The bone-earth thus held dissolved may readily be recovered by neutralizing the acid solvent with an alkali, such as ammonia or lime.

It appears from the facts thus stated, that bones are composed of two distinct substances which interpenetrate one another. There is as it were a skeleton of the earthy matter, which is called phosphate of lime, or bone-earth, and a flesh of the organic matter, which is called ossein; sometimes, though less properly, it is called gelatine. The term "collagen" includes ossein, as well as other animal matters, which are capable of being converted into glue or gelatine by long-continued boiling with water. This organic matter amounts to from a quarter to a third of the weight of the original bone.

Bone-ash.

As regards the action of these two components of bone, in case they were applied to the land as manure, a strictly methodical treatment of the subject would seem to require that the merits of bone-ash should be discussed in the first place, since the action of this substance must evidently be simpler than that of bone-meal, inasmuch as the ash is in no wise complicated by the presence of organic matter.

It will be enough, however, to say of it in this place, that bone-ash is probably dissolved by carbonic-acid water in the soil, and conveyed directly to the plant; or that the solution is first decomposed by compounds of iron or of alumina in the soil, and that the iron or aluminum phosphate thus formed is dissolved in its turn

either by carbonic-acid water or by exudations from roots, and so conveyed to the plant. But bone-ash is not much used as a manure nowadays, for it is, in most soils, supposed to be inferior to bone-meal, although there is no reason to doubt that it could be used with profit in some cases. And it is true that pretty much all that can be said of bone-ash may be said as well, and more conveniently, under the head of bone-black.

Bone-ash is largely imported into England, and to a small extent into New York also, for making superphosphates. It comes from South America principally, though a little is carried to England from the Danube. Bones make a hot fire, as was found long ago by the old navigators who wintered on Spitzbergen and Nova Zembla, and it appears that they are often used for fuel on the treeless plains of South America. Darwin, in his Narrative of the Voyage of the Beagle, in describing a locality on one of the Falkland Islands, says: "The valley was pretty well sheltered from the cold wind, but there was very little brush-wood for fuel. The Guachos, however, soon found what, to my great surprise, made nearly as hot a fire as coals; this was the skeleton of a bullock lately killed, from which the flesh had been picked by the carrion-hawks. They told me that in winter they often killed a beast, cleaned the flesh from the bones with their knives, and then with these same bones roasted the meat for their suppers." Inasmuch as it is much more compact and manageable than bones, — besides being more concentrated in the chemical sense, — bone-ash can be transported comparatively easily. That is to say, it can be brought on the backs of mules from places somewhat distant from tide-water, in regions where carriage is so difficult that it might cost more than the bones would be worth to bring them out as such.

Bone-meal.

Bone-meal differs from bone-ash very materially, because of the ossein which it contains. This ossein is to all intents and purposes flesh. It is in fact a highly nitrogenized substance; and all that can be said of the nitrogenized manures will apply to it.

When bone-meal is buried in moist earth, the flesh-like ossein soon putrefies, and yields ammonia or some other assimilable nitrogen compound, to the very great advantage of the crop, provided it be growing upon a soil that contains plenty of potash, and the other kinds of plant-food. But besides acting by virtue of its nitrogen, the ossein is valuable as an easily putrescible organic substance,

which helps somewhat to dissolve the bone-earth, both by means of the carbonic acid which results from its decomposition, and by the solvent action of the other products that are formed from it.

Bone-meal is used particularly for turnips of all kinds, and for other roots, for tobacco, and for potatoes. Speaking in general terms, it is used for hoed crops rather than for grain. In connection with some potassic manure, it is an excellent top-dressing for mowing-lands and pastures that are not too dry.

Bone-meal and Wood Ashes.

Many farmers living in New England have found that mixtures of bone-meal and wood ashes serve them an excellent purpose when used as substitutes for farmyard manure. On good land, the materials are applied at the rate of 500 or 600 lb. of bone-meal to the acre, together with 15 to 25 or 30 bushels of the ashes, though sometimes on mowing-fields, especially such as are in urgent need of refreshment, as many as 40 bushels of ashes are used with the bone. Occasionally the bone-meal also is applied with a more liberal hand, even to the extent of 1,000 lb. to the acre. The mixing of these materials is easily accomplished by putting them in a "manure-spreader" wagon, layer by layer, taking care not to load into the wagon at any one time more of the two fertilizers than will be just sufficient to cover the land at the rate which has been determined upon beforehand.

Efficacy of Bone-meal.

According to Saxon experience, and Saxony has soils that are commonly not deficient in potash, a cwt. of fine bone-meal is worth as much as 25 or 30 cwt. of manure as obtained from cow stables. It has often been found advantageous to use a small proportion of Peruvian guano at the same time with bone-meal, and an old French practice of causing bone-meal to ferment by keeping heaps of it moistened with urine was based on a kindred thought. Sometimes it has been found advantageous to mix bone-meal with superphosphate even. But the admixture with potassic fertilizers is clearly the better plan, in most instances.

European writers urge that bone-meal does its best service upon soils that are neither too light and dry, nor too close and wet. Both air and moisture are necessary in order for the fermentation and solution of the bone-meal. It often fails to be of much service on stiff clays, and as a rule appears to be better adapted to lighter soils, provided they are adequately supplied with moisture. Gener-

ally speaking, bone-meal would doubtless answer a good purpose on land newly broken up, and rich in decomposing organic matters, provided the land were neither too stiff nor too dry. So, too, when other conditions are favorable, bone-meal will be likely to do better on land full of refuse from a previous crop, such as clover stubble, for example, than on land that has been closely cropped, as by flax. It will naturally do well in conjunction with stable manure used in smaller quantity than if it were not thus reinforced. In New England, it was recognized long ago, by practical men, that bone-meal should not be applied to dry soils. It is esteemed in this region, however, for light soils that are fairly moist.

Varieties of Bone-meal.

Much might be said of the various kinds of bone-meal, and of the methods which are employed either for reducing bones to powder, or for preparing them to be powdered. The subject is an interesting one, and worthy of careful study; and it is wellnigh certain that the superphosphates which are now so prominent will never replace bone-meal for all cases, or drive it from the market. In spite of all that has been said and written in past years in favor of converting bones to the condition of superphosphate, there is hardly any doubt that bone-meal will continue to be used as a manure, for it has its own peculiar characteristics and advantages, and the proper ways and places in which to employ it will no doubt be accurately formulated in the course of time.

The old practice of bone-grinding is not only likely to persist, but to be greatly extended, and it will probably come to pass finally that only the mineral phosphates and spent bone-black will be used for making superphosphate, and that all the bones procurable will be applied to the land in the form of fine powder.

At all densely populated places, great quantities of bones are continually collected; and the working of them over into oil, "ivory," bone-meal, and sometimes gelatine, is a considerable branch of industry. I am told that in Boston the provision dealers commonly get from one half to three quarters of a cent per pound for green bones, — the lower price being paid in case the renderers call for the bones at the meat-shop, and the higher price when the bones are delivered by the provision dealer, either at the works or at some central point in the city.

The old method of crushing the bones to coarse fragments between steel rollers has no longer any particular interest, excepting

in so far as it may still be employed as a preliminary movement to make the bones fit to be ground in mills. When thus crushed, it is perfectly possible to grind dry bones between millstones, as if they were grain. With raw bones the grinding is difficult, particularly if the bones are fresh, since in that event they lubricate the stones; but old, dry bones, even if they be raw, can be ground to a satisfactory powder between the hardest French buhrstones; and bones that have been steamed can be ground between stones of almost any kind.

In Germany, formerly, a common way of proceeding was to stamp the bones, as if they were so much ore of copper or of lead, i. e. pound them to powder beneath a set of stamps moved by water-power. The stamps consisted of a number of long wooden pestles shod with steel, which, by means of a sort of trip-hammer arrangement of cams, were made to play up and down in an iron trough which was the mortar, and into which the bones were thrown. At the sides of this trough there were numerous fine holes through which the bone-meal sifted as fast as it was produced. This process has merit on account of its extreme simplicity. The first cost of the establishment is small, and the stamps can be operated with but little oversight wherever there is a small fall of water.

When the bones are raw it is not easy to stamp them completely to powder, for portions of the bone remain so tough and elastic that they cannot be broken. This difficulty may be obviated for the most part by steaming the bones strongly beforehand. Indeed, it has long been customary, in well-regulated establishments, to steam the bones before grinding or stamping them; or, in default of facilities for steaming, it helps matters somewhat to remove a part of the fat by merely boiling the bones in water. After the steaming, the bones need to get thoroughly dry before the grinding process is proceeded with.

Bones from different parts of an animal differ widely as to their hardness and toughness. It is said that ribs and heads may be ground with comparative ease, even when fresh, and they are so ground near Boston to be sold as food for poultry. But there is no use in trying to grind the tough leg and knee bones of oxen in the raw state. Such bones can be ground, it is true, but only slowly and with difficulty, and the product would hardly be worth the cost of making it. Hence the importance of steaming such bones to destroy their toughness.

Raw Bones and Steamed.

Contrary to what might be thought at first, and indeed contrary to what has often been taught, it appears that the meal from steamed bones, unless they have been very strongly steamed to extract the ossein, as happens in some processes of glue-making, is really better for agricultural purposes than that from raw bones, or even that from bones which have been boiled.

The meal from raw bones has the demerit of containing the natural fat or oil. This fat is not only useless to the plant, but it clogs the meal and hinders it from undergoing putrefaction and solution. It may even be true, perhaps, that the fat can combine with lime or iron in the soil to form an insoluble soap, which then incrusts the meal. Even in case a part of the fat has been removed, by boiling the bones at the ordinary pressure of the air, the unchanged ossein of the meal ferments but slowly, and the action of the manure is slow.

When, however, the bones are placed in a close boiler and subjected to steam pressure, — i. e. to heat powerful enough to melt out all their fat and a portion of their ossein also, — then the bones not only become so friable that they can be cheaply reduced to fine powder, but the chemical character of the ossein left in them is changed. It is changed withal to such an extent that the meal decomposes quickly in the earth, and acts as a quicker and more powerful manure than meal from raw bones which has been sifted through sieves of the same dimensions. As the German writers put it, the meal from steamed bones seems to be "of a finer nature" than the raw meal. It is true, that the quantity of nitrogen in bones that have been steamed in this way may be two or three per cent less than that in raw bone; but nevertheless the meal from steamed bones has practically proved itself to be better than that from ordinary bones.

Not only that, but in experiments made in Germany for the purpose of contrasting the steamed bone with superphosphate made from bones, the steamed meal has often been found preferable to the superphosphate, account being taken of the efficiency and the cost of the two kinds of fertilizers.

From the very fact of its being a chemical product, the superphosphate will necessarily cost more than the mere meal. In fact, while a ton of bone-meal commonly costs some $40 or $45, a ton of bone superphosphate costs from $50 to $60. But the bone-meal

contains more phosphoric acid than the superphosphate, because the gypsum that is formed in making the latter necessarily dilutes its phosphatic constituent.

Several of the experiments in which the meal from steamed bones excelled bone superphosphate are set forth on page 344 of Vol. II. of Heiden's "Düngerlehre."

Meal from steamed bone has finally gained firm ground in Europe, and in some parts of this country also, both as against the meal from raw bone, and as a special manure of peculiar merit.

In large establishments, both the fat and the glue obtained from the bones are put to the ordinary technical uses for which these substances are valuable, so that the cost of steaming is more than offset; but in the case of small local stamps, the glue is usually neglected, or the solution of it is used directly as a manure upon grass land, or for the preparation of compost with peat.

Latterly, instead of steaming the bones, the fat is sometimes dissolved out from them by means of naphtha, whereby a more complete removal of the fat is accomplished without changing in any way the ossein or the bone-earth. Indeed the percentage proportion of nitrogen and phosphoric acid is larger in bones that have been leached with naphtha than it is in raw bones, in accordance with the amount of fat which has been removed.

Little local stamps for preparing bone-meal were not uncommon in Saxony in the days when railroads had not yet been built. I had myself opportunity to visit several of them as recently as 1856. They were at one time encouraged by the local agricultural societies as a means of improving agriculture by bringing a new kind of manure to the farmer's door, and of suggesting to him the utility of using more fertilizing materials than could be obtained from his cattle. The cost of transporting any article so heavy as bones is of course large, and there was at one time a real advantage in having such local stamps. They led to the collection and use of many bones which would otherwise have been wasted, but nowadays the work of grinding bones can be better done in large establishments, excepting of course such bones as each farmer may find time to treat for himself, with alkalies, as will be described directly.

The fineness of the meal to which bones are ground is a very important consideration. Not so very many years ago it was the custom to use crushed bones, and an article is still sold under this name in Boston, though it is chiefly used for feeding to poultry

and milch cows. But there is no longer any question that fine meal is greatly to be preferred to that which is coarse. The finer the meal, so much the more readily will it putrefy and dissolve in the earth, so much the more quickly can the plants be fed by it, and so much the sooner and the more surely will the value of the crop be increased.

Slow-acting Manures are objectionable.

As regards the endurance of the manure, that is to say, the continuance of its action through several years, it is questionable whether even the finest bone-meal is not too enduring, or, in other words, too slow of action.

The old notion, that those manures are best which make themselves felt through a long series of years, is now recognized to be an error. The adage, that "one cannot eat the cake and have the cake," is conspicuously true in agriculture; and just as it is the part of prudence in household or maritime economy to abstain from laying in at any one time more provisions than can be properly disposed of in a year or during a voyage, so should the farmer refrain from bringing to the land an unnecessary excess of plant-food. Such food is liable to spoil withal in the soil, as well as other kinds of provisions that are kept too long in store. A just proportion of food, properly prepared, is the point to be aimed at always.

In general terms, it may be said that an enduring manure is enduring only in so far as it is inaccessible to the crops, excluding, of course, the case where so much manure has been applied that the crops cannot possibly consume the whole of it.

It may be accepted as a truism, that, if the farmer will use artificial fertilizers successfully, he must be at pains to have them prepared properly and so to dispose them upon his fields that he may get back in the crops, in the shortest possible time, not only the interest of the money that has been expended in buying the fertilizers, but the principal itself. Indeed, most of the artificial fertilizers are so costly, that they need to be managed with care, good judgment, and knowledge, in order that due profit may be got from them.

So clearly are the advantages of quick action now recognized, that the comparatively speaking soluble superphosphate of lime has come to be substituted to an enormous extent for bone-meal, as will be explained directly.

Floated Bone.

One idea was to reduce bones to an impalpable powder; and large quantities of bone-flour of extraordinary fineness — so fine indeed that it actually floated in the air — were prepared in Boston some years since by the patent pulverizing machinery of Mr. Whelpley. The process consisted in whirling the bones against one another so rapidly and forcibly that they were ground to the finest powder, somewhat on the same principle that stones are rubbed down to sand or mud upon a shingle beach, except that with the bones the friction occurred in the air, instead of in water, and that there was hardly any limit to the degree of fineness which was easily attainable, until the dust actually floated in the air. This product was sold under the name of "floated bone," at very high prices. It was prepared almost exclusively from raw bones, in the belief, which may perhaps have been true enough in respect to meal so fine, that it is better to retain in the meal all the nitrogen of the original bones.

This floated bone was a powerful manure well suited for green-house horticulture; but it was ill adapted for use in the field, since, unless thoroughly admixed with damp loam before strewing it, a large part of it blew far away, even if no more than a breath of wind were stirring. Perhaps there are not half a dozen days in the year calm enough to permit of this material being properly scattered by itself. It is apt to float away into the air, like so much smoke. The lesson is an instructive one, as teaching how the fineness of bone-meal has to be limited to a point of greatest convenience, all things considered. Bone-dust so fine as this is exceedingly liable to putrefy. Fine flour of bone has to be salted like so much flesh before it can be packed in barrels.

Indeed, most samples of bone-meal are salted to preserve them, though some bone-grinders in this country are accustomed to mix a considerable proportion of salt-cake (or nitre-cake) with their products instead of common salt. It is said that bones so damp and soft — "wet" as the term is — that they could not be handled or transported by themselves, may be brought into merchantable shape by means of this admixture. Doubtless a small proportion of the bone is corroded by the acid salt-cake, with formation of a little superphosphate of lime at first and diphosphate of lime afterward. Hence it happens that a part of the phosphoric acid in bone-meal which has been admixed with salt-cake is rather more soluble than

that in pure bone-meal. To countervail this advantage, however, there is less phosphoric acid and less nitrogen to the ton in the salt-cake specimens, simply because the bone-meal has been diluted by the salt-cake.

Grades of Bone-meal.

At the New Haven laboratory, it is customary to distinguish five grades of fineness in bone-meal, as determined by sifting weighed samples through four sieves. All the meal that passes through a sieve whose meshes measure $\frac{1}{50}$ of an inch is called "fine," and the nitrogen and the phosphoric acid in it are estimated to be worth $0.18 and $0.06 the pound respectively. Whatever passes through meshes that are between $\frac{1}{25}$ and $\frac{1}{12}$ of an inch is called "medium," and the nitrogen and phosphoric acid are rated at 14 cents and 5 cents the pound, while everything larger than $\frac{1}{8}$ of an inch is called "coarse," and its nitrogen and phosphoric acid are rated at 10 cents and 4 cents. The intermediate grades are called "fine medium" and "coarse medium," and their fertilizing constituents are rated at 16 cents and $5\frac{1}{2}$ cents, and 12 cents and $4\frac{1}{2}$ cents respectively.

It is found that, when bone-meal is adulterated or contaminated, the foreign matters are apt to be present in the state of fine powders which pass through the sieves with the finer portions of the meal, during the sifting process. This circumstance must be kept in mind and allowed for by the purchaser of bone-meal when examining samples.

Composition of Bone-meal.

According to Heintz, clean dry leg bones of oxen and sheep contain 6 or 7% of carbonate of lime, 58 to 63% of phosphate of lime (say $28\frac{3}{4}$% P_2O_5), 1 or 2% of phosphate of magnesia ($1\frac{1}{3}$% P_2O_5), about 2% of fluoride of calcium, and 25 to 30% of organic matter.

Payen and Boussingault found $6\frac{1}{4}$% of nitrogen and 8% of water in raw bones; and $5\frac{1}{3}$% of nitrogen and 30% of water in steamed bones as they came from the rendering vats. When dry, the steamed bones contained 7% of nitrogen and $7\frac{1}{2}$% of water.

Heintz's figures afford little evidence as to the composition of bone-meal as it occurs in commerce, for the quality of different samples varies widely. Even bones themselves vary in composition according to the kind and age of the animal from which they came; and those obtainable in commerce are sometimes contaminated with as much as 10 or 12% of sand, and some 8% of water. Hence the amount of phosphates in them may range from 44 to 60%, and the nitrogen may vary considerably as to its value.

According to S. W. Johnson, the nitrogen in hard raw bone is considerably more soluble and decomposable than that in the mixture of soft bone, cartilage, muscular tissue, and grease which makes up "kitchen bone," so called; and as a rule the hard firm bones contain more nitrogen and more phosphoric acid than the softer kinds which are wet and greasy. Such damp, soft bones are often discarded by manufacturers of bone-black as unsuitable for their purposes, and subsequently converted into bone-meal admixed with plaster of Paris or salt-cake, or some such material, which has been used either as a drier or preservative, or for both these purposes. "Kitchen bones," moreover, and all bones that have been gathered by bone-pickers, are apt to have sand or loam adhering to them, or lodged in their cavities; and at the mill itself it is customary occasionally to throw in inert matters of one kind or another, to clear the grinding surfaces.

Besides the driers and preservatives already mentioned, bone-meal often contains small quantities of ground oyster-shells, coal ashes, waste lime, plaster of Paris, coal, or loam. From all of which it appears that the terms "ground bone" and "bone-meal" are applied properly enough to products which may vary to no inconsiderable extent both as to their composition and their value. There is a limit of tolerance, however, as regards these extraneous matters, and Prof. Johnson has urged that any bone-meal which contains less than 19% of phosphoric acid, or more than 5% of matters insoluble in strong acids, should be regarded as an adulterated article.

Valuation of the Phosphoric Acid in Bone-meal.

It is not altogether easy to determine what value should be set upon the pound of phosphoric acid as it exists in bone-meal, because it is hard to say precisely what value should be allowed for the nitrogen which the bone-meal contains, and because the condition of the phosphate in bones is somewhat peculiar, in that it is rather more readily soluble in water and in carbonic-acid water than the phosphoric acid in bone-black.

It is safe enough, however, to allow for the pound of phosphoric acid in bone-meal a value somewhat higher than that for which the pound of phosphoric acid can be bought in the form of bone-ash or bone-black. As prices go, this assumption would make the phosphoric acid in bone-meal come to at least 5 cents the pound, and, as was just now said, the New Haven station allows 6 cents for the pound of phosphoric acid in fine bone-meal.

Bone-meal, such as analysis has shown to carry 23% of phosphoric acid and 4% of nitrogen, can usually be bought at \$40 the ton, and the price of the nitrogen in it will appear from the following calculation. There will be in the ton 460 lb. of phosphoric acid, worth (at \$0.06) \$27.60. But \$40 — \$27.60 = \$12.40, as the cost of the 80 lb. of nitrogen, i. e. 15½ cts. the pound, which is a not unreasonable price to pay for this kind of nitrogen.

If, on the other hand, the sample of bone-meal under consideration should contain no more than 17% of phosphoric acid and 2% of nitrogen, for example, the price per ton would have to be much less than \$40 in order that the material should be fairly profitable to the farmer; for although the 340 lb. of phosphoric acid in the ton of this meal may be worth \$20.40 on the assumption of 6 cents to the pound, as before, the 40 lb. of nitrogen would be worth no more than \$7.20, even if it were admitted that each pound of the nitrogen could be valued at 18 cents.

Many years ago Stoeckhardt found, on comparing all the field experiments on sugar beets that had been published in the course of seven years, that bone-meal had given better crops than superphosphate in 17 experiments out of 32, and better than rape cake in 15 out of 30; while superphosphate did better than rape cake in 17 trials out of 25, though it is not in evidence that either of the fertilizers had been used under the conditions best suited to it.

Solubility of Bone-meal.

Voelcker has determined the solubility of various kinds of bone-meal in water, as stated in the following table. It appears that there are wide variations as to solubility among different kinds of bone-meal. The phosphate in meal from hard bones, even when very fine, is less soluble than that from porous, spongy bones. The fat of raw bones hinders their solution, and their decomposition also. Putrefying bone-meal is more soluble than that which is fresh. As has long been known, certain soluble organic matters and ammonium salts that are formed during the decay of bone-meal promote the solubility of the phosphates that are contained in it.

When water was made to act upon the various samples of meal, there were found dissolved in each 10,000 grams of the water the specified amounts of phosphate of lime and of nitrogen.

	Terphosphate of Lime. grm.	Nitrogen. grm.
Very fine meal from very hard bones that were raw and contained some fat, first extract	0.090	1.298
Same, second extract	0.100	0.200
Coarser meal, chiefly from hard bones (raw as before), first extract	0.351	1.891
Same, second extract	0.301	0.783
Very fine meal from softer bones (raw as before), first extract	0.399	0.898
Same, second extract	0.299	0.299
Same, third extract	0.399	0.100
Half-inch spongy bone, free from fat, first extract	0.800	3.893
Same, second extract	0.349	0.620
Steamed bone-meal, first extract	1.297	1.000
Same, second extract	0.400	0.500
Same, third extract	0.242	0.449
Ivory meal, first extract	0.648	0.978
Same, second extract	0.349	0.489
Bones that had been strongly boiled, residue from glue-making, first extract	0.598	2.495
Same, second extract	0.299	0.299
Same, third extract	0.306	0.254
Putrefying bone-meal, first extract	2.895	4.092
Same, second extract	1.497	0.700
Same, third extract	0.898	0.499

Bone-Black.

In connection with bone-meal, or rather with bone-ash, there is another product to be considered, viz. "bone-black," or bone charcoal. This substance is prepared in enormous quantities for the use of the sugar refiners, and after it has served their purposes it may often be bought at a price which puts it within the reach of the farmer. In the vicinity of many large cities spent bone-black may perhaps be regarded as the cheapest source of phosphoric acid for the farmer, all things considered.

When bones are strongly heated, under such circumstances that air has free access to them, they burn to mere white ashes (bone-ash). But when broken bones are put into iron cylinders, to the interiors of which the air has no access, and are there heated by fires beneath the cylinders, the bones are subjected, of course, not to a process of burning or combustion, but to "destructive distillation," and quantities of gas, water, tarry and oily matters, and ammoniacal products, are driven off from the bones, while black bone charcoal is left in the cylinders.

This bone charcoal consists of bone-earth most intimately admixed and covered with charcoal, which has resulted from the destruction of the ossein that was contained in the original bone. Fresh bone charcoal is a very porous substance, well fitted for removing coloring matters from liquids; hence its use for clarifying brown sugar and many other chemical substances. After the bone charcoal has served the purposes of the sugar refiners, and become "spent," it may be bought at a low price for agricultural use.

From near the beginning of this century until quite recently spent bone-black, as it came from the sugar refineries, played a very important part in the development of French agriculture, notably on the western seaboard in the region about Nantes, where enormous quantities of the material were used much in the same way that bone-meal and afterward superphosphate of lime were used in England during the same period. The sources whence the French farmers were supplied with this fertilizer were not by any means confined to their own sugar-houses, for during many years spent bone-black was regularly imported into France both from America and from Russia, to be used directly for agricultural purposes.

This prejudice of the French farmers in favor of using bone-black rather than bone-meal was peculiar. At first sight their practice seems to have been not wholly intelligent, though something may no doubt be said in favor of it. Unquestionably, in the beginning, when spent bone-black of super-excellent quality could be had from their own refineries almost for the asking, the French did well to use that substance freely. The only point questionable is the propriety of their afterwards using an inferior kind of bone-black, and continuing to use it so long as they did, instead of bone-meal or superphosphate.

Still, it should be said that bone-black was used in France, not for high farming, such as in England justified the use of the more costly bone-meal and bone superphosphates, but chiefly for the production of buckwheat, which is a crop of very low value, comparatively and commercially speaking. It may well be true, that for this particular purpose, and for the time and locality in question, spent bone-black may have been better, all things considered, than either bone-meal or superphosphates. Now that plain superphosphates are to be had at cheap rates in France, they are said to be largely used by the buckwheat farmers. In any event, the history of the use of bone-black in France teaches a very instructive lesson,

which the student will do well to consider, as set forth in the works of Bobierre and Malaguti.

Bone charcoal, when freshly prepared, contains no organic matter that is useful to plants. It would be valuable as a manure only because of the bone-ash which is contained in it. As in bone-ash proper, so in bone-black the bone-earth is so open and porous that it may be regarded as finely divided and apt for the solvent action of plant roots, or of chemical substances in the soil-water. But as with bone-ash, so here the absence of the easily putrescible flesh-like ossein makes the material less soluble and less valuable as a manure.

But the bone-black used in French agriculture was not the freshly prepared charcoal. On the contrary, it consisted of various residual products obtained at the sugar-houses after the bone charcoal had served its purpose of clarifying and decolorizing syrup. These products differed considerably both from the original charcoal and from one another, accordingly as blood had or had not been used by the refiners as an adjunct to their processes of clarification. Where blood was used, the spent bone-black, admixed with the coagulum of the blood, might contain as much as 8 or 10, or even 14% of nitrogen, though generally speaking the proportion of nitrogen was no more than perhaps a third of these amounts. Such materials as these were manifestly fit to be put into competition with bone-meal.

Nowadays the sugar refiners prefer to use bone charcoal in a rather coarse condition, like fine gravel; but formerly it was much more finely powdered, and was consequently more valuable for agricultural use. There can still be obtained from sugar refineries small quantities of coagulated blood, admixed with various impurities derived from the raw sugar, together with a little bone-black. This substance is a powerful and valuable nitrogenized manure, well worthy the attention of farmers in the immediate vicinity of the refinery; but the amount of it is small, and it must not be confounded with the spent black of former days, such as is now under consideration.

In any event, even when no blood is mixed with the syrup, bone-black absorbs a certain quantity of mucilaginous nitrogenized matters from the solution of brown sugar, so that the black may contain after use one per cent, or perhaps one and a half per cent of nitrogen; and the French farmers could formerly buy black in this

condition as well as that which was more highly nitrogenized. It is noteworthy that, among other things absorbed from sugar solutions by the charcoal, there is often a small quantity of a soluble compound of lime, and an unknown organic acid.

According to Malaguti, writing in 1857, the spent bone-black from the refineries of Nantes generally contained some 2 or 3% of nitrogen, from 54 to 60% of phosphate of lime, and 4 or 5% of carbonate of lime. It was in the form of a fine powder. The Russian and American blacks, as sold in Nantes at that period, contained hardly as much as 1% of nitrogen, but they contained 70 or 80% of phosphate of lime, and 8 or 10% of carbonate of lime.

Phosphate and Carbonate of Lime incompatible.

It may here be said that this carbonate of lime, and that in bone-ash also, tends to impair the efficiency of the fertilizers. For since carbonate of lime is more readily soluble than the phosphate in carbonic-acid water, it protects the phosphate from solution so long as there is any of it left in the soil to use up, or, so to say, neutralize the solvent. Warington found that a very small amount of the calcic carbonate, comparatively speaking, was sufficient to prevent the solution of the phosphate. From a mixture of the two substances, carbonic-acid water at first dissolved the carbonate accompanied by only a trace of phosphate; and it was only after the carbonate had been gradually removed that the phosphate freely entered into solution.

French writers upon agriculture have long been accustomed to insist that neither bone-black nor any other form of phosphate of lime should ever be applied to a field which has been recently limed. They urge that bone-black has always been found to be comparatively useless upon soils naturally calcareous; and they argue, as was just said, that the lime carbonate, by absorbing carbonic acid and the other acids in the soil, will hinder, or even prevent, these solvents from acting upon the phosphates. In point of fact, it has been demonstrated by experiments made in several laboratories, that from a mixture of carbonate and phosphate of lime carbonic acid will dissolve the carbonate of lime first, and will not much act upon the phosphate of lime so long as there is any of the carbonate present.

Spent Bone-black is now practically Non-nitrogenous.

It is a long while since those varieties of spent bone-black that were admixed with nitrogenous matters could be obtained in large

quantities, as for many years it has been the custom of sugar refiners to "revivify" the spent black, as the term is, and so use it over and over again. To this end, the spent black is put again into the iron cylinders, and redistilled, as if it were the fresh bone. Sometimes the material is digested in dilute muriatic acid after the distillation, in order to make it more porous by dissolving out carbonate of lime and a part of the bone-ash from the charcoal; and sometimes it is boiled with a solution of caustic soda or carbonate of soda to dissolve out gypsum which accumulates in the pores of the coal and clogs them; but usually the distilled product is simply sifted and the finest powder discarded.

It is this fine, practically non-nitrogenous powder that constitutes the spent bone-black which is procurable nowadays. When of good quality, it may contain some 30% or so of phosphoric acid, as will be shown directly. The foreign blacks analyzed by Malaguti, as above stated, had perhaps been revivified, or used without any addition of blood, while the French blacks appear at that time not to have been revivified at all, so quick was the demand for the spent material among the farmers of the neighborhood. Probably the practice of revivifying bone-black was not adopted by the sugar refiners at Nantes so early or so generally as it was in other countries. Since, looking from the sugar boiler's point of view, bone-black suffers a certain amount of deterioration every time it is revivified, the refiners formerly were probably not unwilling to sell the material after it had been redistilled a certain number of times, particularly in cases where there was a good demand for the spent black to be used as a manure. But in large manufacturing establishments it is so important to have all the processes of manufacture systematized and methodized to the utmost, that the practice has finally become general to use the bone charcoal over and over again so long as it can be used, with repeated revivifications, and to discard only that which has become utterly worn out, viz. the fine siftings.

In the French practice it was the fine nitrogenized black above described that was found to be especially effective for the growth of buckwheat, and it was for the cultivation of this grain that almost the whole of the bone-black sold at Nantes was used.

French writers recommend that the coarse varieties, which contain little or no nitrogen, should be applied to land newly broken up; the argument being that the carbonic acid and other acid pro-

ducts resulting from the decomposition of the vegetable matter will dissolve the phosphate of lime. Malaguti even laid stress upon the action of the sugar which the French spent black held in its pores. According to this chemist, and his argument is perfectly reasonable, a mixture of phosphate of lime and of dried blood will not produce so good a result when used as a manure as a quantity of spent bone-black equally rich in phosphate of lime and nitrogen, for the small quantity of sugar in the spent black will ferment in the soil, and produce acetic and lactic acids, and the like, by which the phosphate of lime will be made soluble, and available as plant-food.

Bone-black, even more emphatically than bone-meal, was regarded as a lasting manure. The good effects of the application of it could be seen and felt for several years. But as has been said already when speaking of bone-meal, this slowness of action is in one sense an objection to the use of any manure. It is not well for the farmer to have his capital lying dead in the earth for several years. When a high-priced manure is applied to the soil, it is in some sort a necessity of the case that a quick profit must be returned.

Hence it happened in England, and in the other countries where agriculture is well advanced, that bone-black was never much esteemed, and that even bone-meal fell at one time into comparative disuse. It is on this account that even in France bone-black has finally fallen into disuse, and has latterly been superseded in good part by superphosphates which are now regarded in that country as almost a specific for buckwheat.

Beside the sugar refineries, there is another very subordinate source of bone-black at some iron founderies, where ground bone is used for case-hardening small castings. The bone being distilled in the process, bone-black is left, which is often thrown away or to be had at a low price.

Spent bone-black is so much more highly esteemed by the manufacturers of fertilizers in this country than most kinds of rock phosphate are, that it is said to be sometimes adulterated, before it is sold to them, with inferior kinds of phosphate rock suitably ground and blackened.

Composition of Bone-black.

According to Morfit, spent bone-black from sugar refineries contains 58% phosphate of lime (= 26½% phosp. acid), 9% carbonate of lime, 19½% (?) carbon, and 4% sand. I have myself found in a sample procured from a sugar refiner in Boston 30% phosp. acid,

6% carbon, and 2¾% sand. Wolff gives the average composition of it as 29% phosp. acid, 8% organic matter, 10% sand, 8% water, and 0.7% nitrogen.

Monier contrasts fresh and spent black as follows: —

	Fresh.	Spent.
Phosphate of lime	81.0	75.5
Carbonate of lime	5.1	16.0
Nitrogenous carbon	10.5	4.0
Silica, etc.	3.4	4.5

Weber, in Germany, who analyzed some 30 samples, several of which were fresh, unused blacks, reports from 50 to 82% of terphosphate of lime, 5 to 10% of carbonate of lime, 1 to 6% of quicklime, ½ to 2% of iron oxide, 9 to 26% of carbon and water, and 2 to 28% of sand, beside small quantities of sodium sulphate and sulphide, and occasionally gypsum and chloride of calcium. Some of these soluble impurities come manifestly from agents used abroad to revivify the coal, as was explained above. In those samples of Weber's black which contained much sand, it seemed to have been added as an adulterant.

Hoffmann, also, in Germany, found in 10 samples of spent bone-black, several of which were of very poor quality, from 11 to 34% of phosphoric acid, 5 to 25% of sand and inert matters, 1½ to 6% of organic matter (? carbon), 0.08 to 0.91% of nitrogen. One sample contained 16% of carbonate of lime, and 0.3% of gypsum; and one was adulterated with powdered peat.

Superphosphate of Lime.

The same kind of reasoning which led to the substitution of fine bone-meal for the coarsely crushed bones of former years has been pushed still further, with the result that a very important branch of chemical industry has grown up, viz. the manufacture of superphosphate of lime from the ordinary phosphate.

In order to make bone-earth still finer than it exists in bone-meal, it became customary some years since in England to treat bones with sulphuric acid, so that a considerable portion of their phosphoric acid might be put into the earth in a condition in which it is soluble in water. Nowadays, not only bones are thus treated, but fossil phosphates of lime in great variety. Indeed, almost the whole of the enormous quantity of superphosphate now used is made, not from bones, but from the mineral phosphates.

Various methods of treating the finely powdered phosphatic

materials with the acid have been employed. One common way is to stir the two together in iron pans, or, better, in a close vessel called the mixer. Sometimes the acid is heated expressly, to hasten its solvent action, though ordinarily the heat developed by the chemical reaction between the dilute acid and the phosphate rock is sufficient for the manufacturer's purpose.

Close mixers, provided with suitable abduction flues to carry off the gases that are evolved, are specially convenient when phosphates that contain an unusually large proportion of fluorides are operated upon. Otherwise, the fumes of fluorine compounds that are given off would greatly inconvenience the workmen. Great quantities of carbonic-acid gas also are given off in some cases, where the phosphate rock contains lime carbonate. Indeed, much carbonic acid is given off even from bone-ash and bone-black, when these substances are treated with acids.

One of the most interesting of the methods of dealing with phosphate rock which have fallen under my own observation may be described as follows. A thin stream of the finely ground phosphate rock is made to flow out from a hopper while a stream of chamber sulphuric acid (i. e. weak acid of 1.45 – 1.6 sp. gr., as it comes from the leaden chambers, and which has never had to bear any expense for concentration) flows down beside it in such wise that both the streams fall together into the top of a tolerably long cast-iron cylinder, that is set in a slanting position and made to revolve constantly upon its long axis. As they flow, or rather twist, down through this slowly revolving cylinder, the acid and the powdered mineral become thoroughly admixed, and they fall out from the lower end in the form of a tolerably thick homogeneous pap, which is thrown into great heaps, each of which contains several cart-loads of the material.

In these heaps, which are left to themselves for several days, considerable heat is developed, thanks to the chemical action of the acid upon the mineral; and a great deal of water is thus evaporated, whereby whatever acid has been left free in the mixture becomes concentrated, as well as hot, and better able to decompose the rock-phosphate. Thus it happens that, towards the close of the operation, a decidedly strong hot acid reacts upon the last, undecomposed portions of the mineral, and the finished superphosphate is left dry and crumbly. It needs only to be crushed to be ready for market.

Weak acid may, of course, be made to act in this way, no matter what mechanical method is employed for mixing it with the powdered rock. It is only necessary that the heaps of mixed materials should be left long enough for them to become hot. The process is noticeably economical of fuel, both in respect to the concentration of the acid used at first, and to the bringing of hot strong acid to act at last on the most refractory portions of the mineral.

No matter what the details of the process may be, the reaction depends ultimately on the formation of a quantity of insoluble or difficultly soluble gypsum by the union of the sulphuric acid with a part of the lime in the phosphatic material. The reaction may be written symbolically as follows: —

$$\underset{\text{(Bone Phosp. of Lime.)}}{3\,CaO,P_2O_5} + \underset{\text{(Sulph. Acid.)}}{2\,(H_2O,SO_3)} = \underset{\text{(Gypsum.)}}{2\,(CaO,SO_3)} + \underset{\text{(Superphosp. of Lime.)}}{CaO,2\,H_2O,P_2O_5}$$

The gypsum, from the formation of which the soluble acid phosphate of lime has incidentally resulted, remains admixed with the soluble phosphate, as a mere diluent. It would be a considerable gain for all parties interested if some cheap and easy method could be devised for getting rid of this encumbrance; for, as compared with the value of the acid phosphate, the gypsum is of insignificant worth as a fertilizer, and the costs of transporting it are much larger than its worth. Of course, the gypsum thus admixed with the superphosphate may often do good service in the field by setting free potash from the soil for the use of the crop, and it has undoubtedly happened in a multitude of instances that superphosphates have on this account actually given better crops than would have been the case if no gypsum had been present. But where potash is thus needed, it would be much cheaper to apply it as such, or to buy gypsum on purpose, and strew it upon the land.

Most of the gypsum in a superphosphate, as well as the other insoluble impurities, might be eliminated by leaching out the soluble acid phosphate with water, and then evaporating the solution to dryness. In this way pure superphosphate of lime has been made that contained some 60% of soluble phosphoric acid, but the process is somewhat costly. There are cases, however, as where the fertilizer has to be transported to some distant and inaccessible locality, where it might be profitable to remove from it all useless ballast.

In like manner, a so-called "double superphosphate" is made at Wetzlar, in Germany, as follows. Rock phosphate, so highly

charged with impurities that it is unfit to be used for making superphosphate in the ordinary way, is finely powdered and stirred up with an excess of highly dilute sulphuric acid. By means of filter-presses, the dissolved phosphoric acid which results from this treatment, together with the excess of sulphuric acid used, is separated from the gypsum and the insoluble impurities derived from the original rock, and the liquid is boiled down in great pans until it is strong enough to be used for treating the better kinds of rock phosphates instead of, or as an addition to, ordinary sulphuric acid. In this way highly concentrated ("double") superphosphates are obtained. The gypsum, etc., that remains in the filter-press is washed with water and sold for a song; and, in order that no phosphoric acid shall be lost, the last washings from the gypsum are said to be used instead of pure water in the leaden chambers where the sulphuric acid is made.

Not easy to make Superphosphate from Bone-meal.

It is noteworthy that it is more difficult to make a superphosphate, rich in soluble phosphoric acid, by treating bone-meal with sulphuric acid, than it is to make it from spent bone-black, or from bone-ash, or even from some of the purer kinds of mineral phosphates.

Sulphuric acid acts but slowly upon bones, unless they are very finely ground. The animal matter of the bone tends to protect the earthy portions from solution. In case the bones are "raw," as the term is, i. e. have not been boiled to remove fat, so much the worse for the superphosphate maker, for the fat even more than the ossein tends to prevent the acid from acting upon the bone-earth. Moreover, both the fat and the animal matter combine with and consume a considerable portion of the acid, and so add to the cost of the product; and, worst of all, they make the product slimy and inconvenient of application to the land.

It is said that, in the later stages of the manufacture, a certain quantity of ammonia is produced by the decomposition of the ossein, and that this ammonia combines with some of the soluble phosphoric acid previously formed, with the result that the phosphate of ammonia reacts upon some of the sulphate of lime in the mixture, and leads to the formation of a quantity of insoluble phosphate of lime equivalent to the amount of ammonia. But, on the other hand, there is an advantage for the farmer, in that the superphosphate obtained from bone-meal contains a certain proportion of

nitrogen in the partially decomposed ossein, as well as some ammonia which has resulted from the total decomposition of the ossein.

As has been said before, it is extremely probable that the demand for bone-meal, added to that of the sugar refiners for bone-black, will ultimately absorb all the bones that can be procured. In the course of a few years there may no longer be any bone superphosphate made for sale excepting such as has been made from bone-black, or perhaps from bone-ash, or from bones that have been steamed under extremely high pressure, for the purpose of extracting ossein, in the process of glue-making.

Composition of Superphosphates.

The composition of really good ordinary plain superphosphates may be stated as follows.*

		Per cent.
From Bone-black	Soluble phosphoric acid	17.3
	Insoluble " "	0.1
" Navassa phosphatic guano	Soluble " "	11.0
	Insoluble " "	3.0
" Carolina rock	Soluble " "	11.0
	Insoluble " "	1.0
" Baker Island phosphatic guano (Heiden, II. 336)	Soluble " "	20.0
	Insoluble " "	2.0
" Bone-meal	Soluble " "	16.0
	Insoluble " "	1.6
	Nitrogen	2.6

Superphosphates much more concentrated than the foregoing may be made by the process described above, or by making sulphuric acid act upon pure precipitated phosphate of lime; either such as may be prepared on purpose, or such as is obtained in Europe as an incidental product in the manufacture of gelatine. It is possible to get in this way superphosphates that contain 34 or 35% of soluble phosphoric acid. A certain amount of superphosphate of a grade as high as this, or even higher, is used in this country by the dealers in fertilizers, for mixing with other superphosphates to bring them up to a required standard, or for preparing mixtures of fertilizers, though as a general rule bone-black superphosphates seem to be used for these purposes of reinforcement.

Analyses of superphosphates containing

Soluble phosphoric acid	32½–35%	and even	39%
Insoluble " "	2–3%	"	7%

were made at the New Haven station in 1883 and 1884.

* Most of the analyses are from the Report of the Connecticut Agricultural Experiment Station, 1884, p. 33.

Mode of Action of Superphosphate.

When a superphosphate is applied to the soil, the first rainfall, or even the moisture of the soil, dissolves the soluble phosphoric acid and causes it to soak into the earth. There it comes in contact with carbonate of lime, and with compounds of iron and alumina, and is arrested by these substances. That is to say, the phosphoric acid is precipitated in the earth, in the form of phosphate of lime for the most part at first, and of the still more difficultly soluble phosphates of iron and alumina. Unless, indeed, the soil is actually deficient in lime, it is not true, as some persons had supposed, that any of the soluble phosphoric acid remains dissolved in the soil-water longer than a few days at the utmost. The tendency always is toward the formation of the difficultly soluble phosphates of iron and alumina. It is only in soils comparatively rich in lime that it is to be supposed that any large portion of the phosphoric acid remains long even in the condition of phosphate of lime.

An experiment of P. Thenard illustrates this matter. He dissolved some phosphate of lime to saturation in carbonic-acid water, and put the liquid in a bottle with a small quantity of soil that had been formed by the disintegration of a Jurassic rock. After the mixture had stood three or four days, no trace of phosphoric acid could be detected in solution. The whole of it had been fixed by the earth. Similar results were obtained when the loam was replaced by alumina or oxide of iron. But since almost all soils contain an abundance of iron and alumina, it is no wonder that the phosphoric acid in manures is firmly fixed in the earth soon after its application.

A. Mayer digested 10 grams of a superphosphate in 300 cc. of water, and added to the clear filtrate 45 grams of precipitated carbonate of lime. The mixture was shaken frequently, and tested at intervals to determine how much phosphoric acid remained dissolved in the water. The following results were obtained. Three hundred cc. of water contained in solution

	Grm. of Phosp. Acid.
Before the carbonate of lime was added	1.26
6 hours after	1.16
24 hours after	1.01
8 days after	0.15
24 days after	0.03

Analogous results were obtained when a calcareous soil was mixed with the solution of a superphosphate. It appeared in fact, as had

been shown before by other chemists, that the phosphoric acid of a superphosphate is only slowly precipitated in the soil, even when the soil is calcareous. In other words, considerable time is allowed for the diffusion of the phosphoric acid in the soil before it is arrested.

When an alkaline carbonate, such as is contained in wood ashes, stable manure, or dung liquor, is added to a solution of a superphosphate, Mayer found that from $\frac{1}{2}$ to $\frac{2}{3}$ of the phosphoric acid is speedily precipitated, while the rest remains dissolved as an alkaline phosphate, from which the phosphoric acid is slowly precipitated when the solution is put in contact with a calcareous soil.

On adding ferric hydrate and hydrate of alumina to solutions of phosphate of lime in carbonic-acid water, Warington found, after some days, that 96 and 97 hundredths of the phosphoric acid had been abstracted from the solutions and deposited as phosphate of iron or of alumina, while the whole of the lime remained dissolved.

Superphosphates are Distributing Agents.

It is to be observed that, although the phosphoric acid which has been made soluble with toil and trouble is reprecipitated in the earth, and is reprecipitated for the most part in a difficultly soluble form, the precipitate is exceedingly finely divided, and very thoroughly disseminated. It is far finer than the finest bone-dust; and, what is still more important, it is distributed everywhere in the soil. The roots of crops are thus provided with a continuous supply of phosphoric acid, and the microscopic organisms which prosper in soils where phosphates abound can everywhere find an abundance of this kind of food.

When bone-meal is applied to the soil, there will always be left numberless places where no bone-meal has fallen, no matter what pains may have been taken to reduce the meal to fine powder or to incorporate it thoroughly with the soil. But the dissolved phosphoric acid soaks into the earth in all directions around every point where a particle of the original superphosphate has come to rest, and there is thus obtained a dissemination of the manure infinitely more perfect than can be had by mere mechanical distribution.

It will be noticed that, in so far as mechanical dissemination goes, the bone-meal and the superphosphate are upon equal terms; either one of them can be mixed with the earth as well as the other; but the distribution by way of solution comes in as something additional and subsequent.

From what has been said above of the chemical character of superphosphate of lime, it follows that this fertilizer should generally be applied to the land long enough before seeds are sown or young plants set out to allow time for the soluble phosphoric acid to become fixed in the soil, so that its acidity may be annulled. Moreover, it is not well to mix superphosphate with loam before spreading it, lest some of the soluble phosphoric acid become fixed in this loam instead of in the soil proper.

Whenever it is possible to disseminate fertilizers through every part of the soil, as can be done in the case of the superphosphates, it is not unreasonable to suppose that the roots of crops can grow continuously and rapidly, — much in the same way that they are seen to grow sometimes in house drains, — without suffering any check or irregularity. But in the contrary case, where the roots have to pass through spaces of earth free from manure, the growth of the plant must necessarily be less regular and less rapid. In the one case, the free growth of the plant will be continuous and smooth, as it were, and in the other, it will be spasmodic and intermittent.

With regard to the manner in which the phosphoric acid which has become fixed in the earth is made soluble again for the use of plants, it will be sufficient to say here, that, among the various means by which this result may be accomplished, the action of carbonic-acid water and of the acid juices exuded by plant roots are conspicuous. The subject will be referred to again hereafter.

Superphosphates may do Harm.

In using superphosphate, a certain amount of care should be exercised, as was said just now, lest this acid substance injure the seed or the young crop. Dr. Voelcker has noticed, in England, that when concentrated superphosphates are used in large quantities, say at the rate of 500 or 600 lb. to the acre, they may do positive harm to root crops, because the soluble phosphoric acid is not all precipitated quickly enough. Even 200 or 300 lb. applied to land poor in lime may do harm in the same way. By good rights, there should be lime enough in the land to precipitate the phosphoric acid pretty quickly, and some time also must be allowed for the precipitation.

Significance of Quick-acting Manures.

One of the best illustrations that can be given of the advantage of using manures that act quickly is drawn from the experience of

English farmers with phosphate of lime in its various forms. A hundred and more years ago, when bones first began to be used in that country, they were applied either unbroken, or, somewhat later, in coarse fragments, at the rate of 10 or 12 cwt. to the acre. Afterwards, when bone-meal came to be manufactured, 6 or 7 cwt. of the meal per acre were deemed to be a sufficient dose; while later yet, 1 or 2 cwt. of superphosphate per acre were found to be sufficient to produce the same effect on some soils and crops. In other words, for a given sum of money, six or eight times as much land can be well fertilized with the improved manure as was possible before.

Though specially esteemed for turnips and other roots, and for Indian corn, it is said that superphosphates have been much used of late years in England for top-dressing barley, being applied at the rate of 200 or 300 lb. to the acre. In the low-lying fen districts, also, superphosphates have been applied with great advantage to oats in the spring.

Superphosphates have approved themselves.

In the last analysis, it is of course always a matter of money value and of comparative efficiency whether the farmer shall use the large amount of crushed bone, as above stated, or the small amount of superphosphate. It was argued at one time, that, even as regards powdered phosphate rock, it might perhaps be better to apply a double dose of the raw material to the land than to pay for the cost of the acid, the labor, and the machinery involved in the preparation of the superphosphate.

The same amount of money, it was said, will probably do more lasting good to the land if it is applied in the form of a large quantity of the powdered mineral, than if the dressing be restricted to the smaller quantity of superphosphate which this sum of money is competent to buy; and it is doubtless true, as regards some kinds of soils, notably reclaimed marshes, moors, and bogs, that powdered phosphate rock may be a better manure, all things considered, than superphosphate of lime. But for Europe at least, i. e. for fertile districts, the question has been decided long ago, and most emphatically in favor of the superphosphate. It has been decided by the long-continued experience of a multitude of farmers, and their conclusion has been plainly expressed by the ever-increasing demand for superphosphate.

There are cases, of course, as where a deposit of mineral phos-

phates of low grade might exist in the neighborhood of a farm together with running water wherewith to pulverize the materials, where it might possibly be best not to buy superphosphate of lime, but to make use of the home material; but an exception such as this is of small importance, and does but tend to strengthen the general argument in favor of buying the active fertilizer in most cases. There are withal special situations, soils, and crops, where an instructed farmer might find it more profitable to use a cheap insoluble phosphate, rather than the costly soluble product prepared from it. This point is one worthy of much consideration, though it relates to a mere question of detail that has not yet been adequately studied.

There was another question that used to be asked in all such speculations, viz. whether it would not be better economy to apply to the land a given money value of the raw material, plus a proper proportion of some nitrogenized or other manure, in place of an equivalent amount of the superphosphate. But this question would seem to have been answered long ago, in so far as good land is concerned, by the common English practice of using superphosphates — but not the phosphatic guanos with which the superphosphates were at one time in competition — in alternation with nitrogen compounds.

Plain Superphosphates.

Plain superphosphates, made from "rock," or "ash," or "black," have the disadvantage, as compared with bone-meal, that they do not contain the flesh-like nitrogenized substance which adds so much to the fertilizing value of the bone. Yet in spite of this fact, and of the cost of manufacturing them, the use of plain rock superphosphates has steadily gained ground during the last 40 or 50 years. The power of disseminating itself in the soil, and the consequent rapid action of the superphosphate, is a point of far greater significance than the cost of making the fertilizer, or than the absence of nitrogenized constituents. It is an easy matter always for the farmer to apply some kind of nitrogenized manure, such as nitrate of soda, or sulphate of ammonia, or fish scrap, or meat dust, or oil-cake, to reinforce the superphosphate, as is often done in England.

Nitrogenized Superphosphates.

Indeed, the American market has long been flooded with a great variety of so-called ammoniated or nitrogenized superphosphates, into which the nitrogen compound has been already put. In most

of these products, the nitrogen exists in the form of fish scrap; in other cases it is in the form of dried blood or tankage. Some specimens contain dried meat, as obtained from the offal of slaughter-houses. Formerly the scraps of flesh and gristle obtained as a residuum in the operation of rendering grease and tallow were sometimes employed; and at times a most improper use has been made of worthless torrefied leather for this purpose. Occasionally some of the nitrogen in these superphosphates is in the form of crystals of sulphate of ammonia, or of nitrate of soda, and in some of the earlier specimens Peruvian guano was detected. A few years since, when nitrate of soda happened to be exceptionally cheap, a good deal of this material was used for reinforcing phosphates.

As a rule, these so-called ammoniated superphosphates are not to be commended. The chief reason why they continue to be made appears to be the ignorance of those farmers who know so little as to the modes of action of the chemical fertilizers that they do not feel competent to decide for themselves which they had better use.

When superphosphates were first made, bone-meal was the raw material. The farmers of those days thus became accustomed to a fertilizer which contained both phosphoric acid and nitrogen, and which could be used as a substitute for farmyard manure on many soils, such for example as were well charged with potash compounds. Hence when bone-black, bone-ash, and rock phosphates began to be used, instead of bone-meal, for making superphosphate, a feeling arose, not unnaturally, that some kind of nitrogenized matter should be added to the product, to compensate for the lost ossein. It was in those early days that Peruvian guano and sulphate of ammonia were sometimes met with in superphosphates, which could then truly be called "ammoniated." But with the advance of agricultural knowledge, superphosphates are nowadays much more generally regarded as distinctly phosphatic manures, and there is no longer any such justification for adding nitrogenous matters to them as there was at first.

Perhaps one explanation of the abundance of nitrogenized superphosphates in the markets of this country may be found in the character of some of the cotton lands of the South. Many of them are said to be deep loams which have resulted from the disintegration of granite, gneiss, and other feldspathic rocks "in place," whereby soils have been formed which are rich in potash and well adapted to withstand drought in many cases. As a rule, these soils

do not run together or "bake" after heavy rains, and they are easily cultivated. But it would appear that they need additions of phosphoric acid and nitrogen, and that they respond quickly to dressings of nitrogenous superphosphate, which is for them a complete manure.

Speaking in general terms, however, it may be truly said that very little knowledge, and still less conscience, have been displayed in past years in the manufacture of the nitrogenized superphosphates in this country, while for a very long period it was customary to sell them at exorbitant prices. Scientifically speaking, the fundamental idea of making them for sale is wrong, in so far as there cannot be much sense in carrying on at a manufactory any simple operation which the farmer can perform for himself just as well as the factory workmen, or better.

It is not to be recommended, as a general rule, that the farmer should attempt to decompose either raw bones or rock phosphates with sulphuric acid upon his farm. As was said before, the manufacture of superphosphate from bones, and from most kinds of rock phosphates also, is a somewhat difficult operation, the successful conduct of which requires manufacturing appliances and chemical skill, i. e. trained workmen. But it can safely be asserted that the mixing of the finished superphosphate with a dry harmless powder, like sulphate of ammonia, or nitrate of soda, or with a friable substance, like dried ground-up fishes, is an operation not beyond the capacity of an ordinary farm laborer. It is a mere matter of spreading the things in layers upon the barn floor, and then turning the mixture over with a shovel, much in the same way that a compost heap would be turned.

The chief advantage to be derived from this home mixing is based upon the facts that nitrogenized manures, such as fish scrap, oil-cake, nitrate of soda, and sulphate of ammonia, are, for the most part, cheap merchantable articles of peculiar appearance. Several of them are so well characterized, and so easily recognized, that it would be a comparatively difficult matter to adulterate them by themselves. But when once mixed with the superphosphate, the identity of the nitrogen compound is lost. Even chemical analysis can scarcely tell how much one of the current ammoniated superphosphates is worth, for there are many substances rich in nitrogen, such as leather scraps, which have no value whatsoever as food for plants, and it is possible to incorporate these things into a nitro-

genized superphosphate so thoroughly that a mere analysis might make the mixture out to be worth far more than its intrinsic value. This remark applies also, though with a trifle less force, to leather which has been steamed or roasted and then powdered, such as will be described hereafter.

Moreover, many good farmers would hold that it is best not to mix the nitrogenized compound with the superphosphate at all, but to apply the one this year to the grain crop, and the other to the same field, next year, for turnips or corn or potatoes; or to add one or the other of the materials to moderate dressings of farmyard manure. It would appear that the last-named plan must often be the best. In the case of corn or potatoes, for example, the superphosphate may be put in the hill; while fish scrap, or oil-cake, or the like, could readily be admixed with the farm manure by scattering it upon the layers of dung in a "manure-spreader" wagon as a part of the process of loading it.

The idea should be to reinforce the dung in one-sided ways, for on fairly good land there is naturally a large amount of plant-food available for crops, and there will be all the more after a light manuring with dung. But by adding to this general store a quantity of the particular kind of plant-food which the desired crop will be most grateful for, or would have most difficulty in obtaining, it will usually be easy to excite vigorous growth. It has been found in England, that there are numerous soils which will give abundant crops of wheat or barley when dressed with nothing but an ammonium salt or nitrate of soda, and there is a still larger number of European soils which will give large grain crops when dressed with nitrate of soda and superphosphate of lime, since there is usually enough potash in those old lands to meet the wants of grain crops. So too, it is said that nitrate of soda alone will often give great crops of beets, and superphosphate alone large crops of turnips, while potash salts alone may sometimes be profitably applied to clover fields, or even occasionally to pastures.

Some experiments made long ago in England by Mr. Pusey, for the sake of determining how large an amount of farmyard manure could be profitably applied to his land, well illustrate the significance of using superphosphate with dung: —

From the Acre of Land upon which had been put	He harvested Tons of Mangolds.	Increase over No Manure. Tons.
No manure	15½	..
13 tons of farmyard manure	27½	12
26 tons of farmyard manure	28½	13
13 tons of farmyard manure, together with 2 cwt. of superphosphate	36	20½

In England it is said that from 4 to 6 cwt. of superphosphate are often used nowadays upon potatoes, in addition to farmyard manure; or, as an addition to nitrogenized manures and potash salts. 1 cwt. of sulphate of ammonia and 2 cwt. of potash salts have been recommended as a proper addition to the superphosphate both for potatoes and for mangolds, though for the crop last named guano is generally thought to be considerably more effective than superphosphate. When used by itself on turnips, as much as 4 or 5 cwt. of superphosphate are sometimes applied with advantage, though for most soils smaller quantities of this fertilizer are commonly preferred.

In this country the use of ammoniated superphosphates seems to have depended at one time largely upon the efforts of manufacturers to eke out the value of improperly prepared plain superphosphates by reinforcing them with another kind of manure. Of late years similar efforts have been made to bolster up fertilizers of low grade by adding potash salts to them, as well as nitrogen compounds.

An example of home mixing has been reported by Mr. Webb, of Connecticut, as follows. Four tons of bone superphosphate, one ton of muriate of potash, and one ton of sulphate of ammonia, were purchased. A bag of the phosphate, weighing 200 lb., was emptied upon the barn floor, and the lumps beaten down with a shovel; 100 lb. of the muriate were poured upon the phosphate; then 200 lb. more of the phosphate were added, and finally 100 lb. of the sulphate of ammonia; the whole being mixed with shovels, sifted, and put into barrels for convenience. The mixture was found to be in excellent order for sowing, and gave great satisfaction in every way. The whole cost of the completed mixture was \$36¼ the ton, and the value of it, as appraised from analysis, was \$48½ the ton.

A peculiar method of making nitrogenized superphosphate, which was employed some years since at a factory in Berlin, may be mentioned as an historical curiosity, though it is by no means evident that the process was either philosophical or economical. At the

establishment in question, the flesh of some five thousand horses per annum was dissolved in sulphuric and nitric acids, and the acid solution thus obtained was used for decomposing bones instead of the raw acid. The superphosphate produced in this way contained as much as 6% of nitrogen, and about 20% of phosphoric acid.

A highly interesting survey of the nitrogenized superphosphates, and of other fertilizers with which American farmers have been afflicted, may be got by reading the annual reports of Professor S. W. Johnson in the Connecticut State Agricultural Reports, and more recently in the Reports of the Connecticut Agricultural Experiment Station. Until comparatively recent years, the most remarkable features of the nitrogenized superphosphates in particular have been their very indifferent quality for the most part, and the unreasonably high prices at which they were sold.

Home-made Superphosphates.

Superphosphate of lime may be made at the farm without difficulty, from bone-black or from bone-ash, but not from bone-meal. The trouble with the last is, that, when treated with acid, it forms a sticky unmanageable mass that can neither be handled nor spread upon the land. In order to do anything with it, much trouble has to be taken in mixing the slimy product with dry earth, or coal ashes, or gypsum, "to dry it"; but, with the exception of the gypsum, either of these substances would do harm in the chemical sense by "fixing" some part of the phosphate that had been made soluble by the acid. It is said that practically not more than one third of the phosphoric acid in raw bones can be dissolved by means of sulphuric acid without making the product too sticky for convenience.

The following method has been commended as giving perhaps the best approximation to good results. Pour 50 lb. of oil of vitriol into a volume of water equal to that of the acid, stirring the water meanwhile with a stick. Pour this diluted acid upon 100 lb. of bone-meal that is contained in a wooden trough, and stir the meal slowly and carefully with a hoe. The product obtained in this way admits of being dried, after a fashion, by stirring it up with earth or with gypsum; but if a larger proportion of acid were used, the mass would be apt to become so very adhesive as to be unmanageable.

By using bone-black, however, no such trouble is met with, and many farmers have prepared excellent superphosphate, with great

economy, by mixing spent bone-black and sulphuric acid even in a mere hole in the ground, as has been set forth, for example, in the Bussey Bulletin, Vol. I. p. 187. Prof. Johnson reports a similar instance where 100 parts by weight of the bone-black, having been spread on a mortar bed, and moistened with 42 parts of water, were treated with 55 parts of strong oil of vitriol, and thoroughly stirred with a hoe. There must have been an unpleasantly tumultuous effervescence in this case, but the product was found to contain 13% of soluble phosphoric acid after it had been left to itself for a week.

A more methodical and agreeable method of procedure has been formulated by Dr. Nichols of Haverhill, as follows. First make a tank of pine planks, four feet square and one foot deep, and line it with sheet lead. There is no trouble in doing this, for a roll of sheet lead of these dimensions, or a trifle larger, may be bought at the lead works, and the sheet may be pressed down into the tank frame, and the metal be allowed to crinkle to suit itself at the corners. Into the finished tank ten gallons of water are poured, and then slowly the contents of a carboy of oil of vitriol (165 lb.), while the contents of the tank are stirred with a stick. Into the acid thus diluted throw gradually from a shovel 380 lb. of spent bone-black from the sugar refinery. There will be a tolerably violent effervescence, due to the escape of carbonic acid from the carbonate of lime that was contained as an impurity in the bone-black. After the mixture has been left to itself for a couple of hours, it will be dry and fit for use.

This process could be used perfectly well for decomposing bone-ash, and powdered phosphatic guano, or even for finely ground rock phosphates of good quality.

As imported from South America, bone-ash contains some 70 or 80% of phosphate of lime. Voelcker's analyses gave an average of 73½%. According to Wolff, it contains on the average 35½% phosphoric acid, 6½% silica and sand, 6% of water, and 3% of organic matter. Bone-ash contains several per cent of carbonate of lime also, which would naturally cause a considerable amount of frothing, as is the case with the bone-black. Pure horse and ox bones gave Voelcker ashes that contained 83 or 84% of phosphate of lime, 2⅓% of phosphate of magnesia, and 7 or 8% of carbonate of lime. Even bone-meal may contain as much as 8% of carbonate of lime.

Bone-black Superphosphate.

It is as true of the factory as of the farm, that it is particularly easy to make good superphosphates from bone-black. The product has the advantage, moreover, that when well made it can be kept indefinitely without undergoing detriment. It was these essential merits of bone-black superphosphates, doubtless, that long ago led many farmers to prefer them to products made from the rock phosphates. Indeed, it is a well-known fact, that, at a time when the making and selling of superphosphates was ill-understood in this country, one or two manufacturers were able to establish a high reputation by simply persisting in using nothing but bone-black as their raw material. They became in some sort masters of the situation, because they could turn out products of constant composition and assured quality, while their competitors were unable to do so. Hence latterly the name "dissolved bone-black" has been used to describe this form of superphosphate. Hence also the fact, that in some sections of the country purchasers much prefer to buy black or dark-colored superphosphates, — a prejudice which has sometimes been gratified by the addition of soot or lamp-black to light-colored superphosphates during the process of manufacture.

Latterly, it appears to have been somewhat customary for the manufacturers of fertilizers to employ bone-black (or bone-ash) to reinforce their inferior superphosphates made from rock. Probably one way of proceeding is first to treat a quantity of powdered phosphatic rock with an excess of sulphuric acid, in order to render soluble the largest possible amount of the phosphates contained in it, and then to add enough bone-black to neutralize the excess of acid, and to make the product dry and merchantable. Perhaps the good bone-black superphosphates are sometimes mixed directly with superphosphates of inferior quality, in order to bring the latter up to a salable standard of quality, in the same way that the high-grade foreign superphosphates are said to be used. It was reported, at all events, a few years ago, at a time when a depression in business caused many sugar refiners in this country to suspend their operations, that so little spent bone-black was then procurable that some manufacturers of superphosphates had considerable difficulty in maintaining their products in marketable condition.

Waste Acid for making Superphosphates.

It is an interesting circumstance bearing upon the cost, odor, and appearance of many American superphosphates, that they are some-

times made with acid that has already been used for purifying petroleum to fit it for being burned in lamps. When strong sulphuric acid is made to act on partially rectified petroleum, it combines with certain impurities therein contained to form a dense tar-like or pitchy product called "sludge," which settles beneath the purified oil. If water is added to this sludge after it has been run off from the petroleum, the tarry compounds are decomposed, and much of the sulphuric acid is set free again. A weak, impure sulphuric acid, smelling strongly of petroleum products, is thus obtained, which, under the name of "sludge acid," is used for making superphosphates. Since the sludge acid costs next to nothing, and can hardly be used for any other purpose because of its vile smell, some manufacturers of fertilizers have found their advantage in making use of it. Some part of the peculiar odor of the petroleum products naturally remains attached to the finished fertilizers.

Methods of Decomposing Bones.

It must not be forgotten that other ways of decomposing bones have been resorted to beside the ordinary method with sulphuric acid. Even before the introduction of superphosphates it was the practice of some European farmers to ferment their bone-meal before applying it to the land. To this end, the meal was left for a time in heaps, which were kept moist with water or with urine, or with barnyard liquor. Sometimes the bone-meal was fermented in heaps of moist earth alone, or better yet with moist sawdust, in the proportion of 2 or 3 parts of the earth to one of bone-meal, and sometimes it was commingled with a mixture of earth and wood ashes, and then kept moist with water or with barnyard liquor during several months. For grass land 30 or 40 bushels of the product obtained from these processes of fermentation were thought to be a sufficient dressing; and upon ploughed land they were used at the rate of 20 to 25 bushels.

There is no doubt that these processes are effective, in that they make the bone-meal act quickly as a manure, but the fermentation is of course liable to destroy a considerable proportion of the nitrogen in the bone. This point has been studied with care by Ulbricht. He mixed 550 lb. of fine bone-meal with 100 lb. of barnyard liquor, and incorporated the whole thoroughly with 1,000 lb. of earth. The mixture was shaken out into a heap some eight inches high, and left to ferment. At the beginning, the temperature of the heap was 63° F., but in the course of 24 hours it went

up to 117°, while ammonia and water vapor were given off freely, and at the end of 48 hours it had risen to 129°. After that, the heap gradually cooled, and at the end of a week the odor of ammonia ceased to be apparent.

Ulbricht analyzed the various components of the heap in the beginning, and he determined the amounts of nitrogen, etc., at different stages of the fermentation. It appeared that 16% of the nitrogen in the original bone-meal went to waste in the course of the first two days of the fermentation, but that afterwards the loss was very small.

The loss of nitrogen could probably be very much lessened by making the fermentation less rapid, as could be done by mixing the meal with a larger proportion of earth or with peat, as will appear when the preparation of composts is described. Kuester, a German farmer, has proposed to save the ammonia by covering the fermenting heap with a layer of superphosphate, but he would in that event make some of the soluble phosphoric acid insoluble. A German receipt for fermenting whole bones with horse manure is as follows. Soak the bones in water for several days, then pack them in a dung-pit layer by layer with horse manure, taking care to moisten each layer with the water in which the bones have soaked, and with other water as well. Each layer of bone should be about 3 inches thick, and the layers of horse manure 12 inches thick. The heap is topped with loam. At the end of ten months the bones will be reduced and the mixture fit for use.

Several receipts for decomposing bones by means of wood ashes have been published from time to time, especially in this country. In cases where few bones are to be had, the commonest plan seems to be to pack them layer by layer with wood ashes in an old hogshead or barrel, and to keep the mixture well moistened during several months. But a better plan, particularly where only small quantities of bones are to be treated, will be to boil them in lye, prepared either by dissolving potashes in water, or by leaching wood ashes. There are many farms where the small quantities of bones obtainable might readily be reduced in this way at very small expense.

I am informed by Mr. W. M. Stone, of Washington, Pa., formerly a student at the Bussey Institution, that he has boiled bones with success in lye obtained by simply leaching wood ashes with water (without any use of lime). At first, the kettle was filled with

the moderately dilute leachings of the ashes, but the liquor naturally became concentrated by the boiling. Whole bones were thus treated. "Even a horse's head was reduced in this way." In this case the liquid or muddy product was poured out upon enough wood ashes to "dry" it, and the mixture was used for manuring Indian corn. Probably it would be better to pour the alkaline product upon heaps of weeds to kill their seeds, and to ferment the vegetable matter, or to use it for fermenting peat or sods, as will be explained under the head of Composts.

A solution of caustic potash would be even more effective than the carbonate for this purpose. According to Ilienkoff, a ten per cent solution of caustic potash acts so strongly on bones that, when a mixture of the two substances is left to stand for a week and is then treated with water, there will be obtained an emulsion consisting of an alkaline solution of ossein with bone earth suspended in it, in a finely divided condition. Similar results may be obtained by means of a mixture of carbonate of potash, caustic lime, and water. Seeking to reduce these laboratory experiments to farm practice, Engelhardt procured 4,000 lb. of bones, 4,000 lb. of wood ashes, 600 lb. of quicklime, and 4,500 lb. of water. He dug a couple of trenches two feet deep, and lined them with boards, and, having slaked the lime with a part of the water, mixed the powdery product with the ashes. Into one of the trenches he put half the bones, viz. 2,000 lb., layer by layer with the mixture of lime and ashes, taking care to wet the materials.

The mixture was left to itself, with occasional moistenings, until the bones had become so soft that they could be rubbed down between the fingers. 3,600 lb. of water were used in this trench, beside that employed for slaking the lime. When the contents of the first trench had become soft, they were spread layer by layer in the second trench with the remaining 2,000 lb. of fresh bones, and the whole was well worked together and then left to ferment until the bones were softened. The mass was then shovelled out, and mixed with 4,000 lb. of dry loam or peat to make it manageable. The dry product should contain altogether some 880 lb. of phosphoric acid, 340 lb. of potash, and 160 lb. of nitrogen. In this country, where labor is so costly, it would certainly be well to omit the operations conducted in the second trench of this experiment.

Probably a better plan in many cases will be to use crude American potashes at once, instead of wood ashes and lime. Several

farmers have reported their successful use of this material. In one case the hard mass of potashes was broken into small lumps with a sledge-hammer, and a strong solution prepared by throwing the lumps into a large kettle of boiling water. This lye was poured upon coarse bone-meal that had been spread upon the floor of a barn cellar, in the proportion of 1 lb. potashes to 4 or 5 lb. of the bone. Much heat is developed at first by the action of the lye on the bone. During the course of the next two or three weeks, the mixture is turned over occasionally, and is then fit for use.

The disintegration of the bone produced in this way is said to be so complete, that any large pieces of bone which may happen to be present will be found to be so friable after the action of the potashes that they can be crushed with the fingers. Bone-meal thus treated has been used with success for fertilizing strawberries, cabbages, grape vines, and pear trees. Mr. W. H. Hunt, of Concord, Mass., reports that he has used as much as a ton of potashes in a year upon bone-meal in this way, and that the fertilizer obtained is excellent.

Although the process is troublesome because of the care which has to be taken in handling the corrosive potashes and the lye prepared from them, he finds the use of this material for reducing bone cheaper than that of sulphuric acid, while the product is much more valuable for his purposes than superphosphates such as he had bought in previous years. Mr. Hunt is accustomed to strew gypsum on the mixture of bone meal and lye, at the time when heat is evolved from it, and when the mixture is worked over also; but, as Hilgard has pointed out, such use of gypsum is not to be commended, since the reactions which occur between this substance and carbonate of potash do actually, and must necessarily, work to destroy the solvent action of the potashes on the bone. A modification of the foregoing method is to put bone-meal in a pit, to pour the solution of potashes upon it, and to cover the mixture with two feet of loam.

Where only small quantities of the material are procurable, it would probably be best simply to boil the unbroken bones in the solution of potashes, and to pour the solution upon peat or weeds, as was said. This method deserves to be carefully studied, at all events, since it promises to be easily applicable to the bones, hoofs, and horn-piths procurable upon a farm or in any country village.

As regards bone-meal, however, when used in considerable quantities, the method of drenching heaps or layers of it with the hot lye will probably be most commendable. Bone-meal is quickly acted upon by wet wood ashes also, and some writers have urged, perhaps rather too hastily, that only a few hours are required to reduce the bone-meal sufficiently in this way. When whole bones are composted with wood ashes, considerable time is needed in order thoroughly to soften them, though the process is nevertheless said to be an economical one under some circumstances.

The following method, taken from a German source, is said to have originated in Russia. In a trench 3 or 4 feet deep, wood ashes and whole bones are piled in alternate layers, each about 6 inches thick. The lowest and the uppermost layers are of ashes, and each layer of ashes is saturated with water as soon as it has been laid. Upright stakes are set in the trench at intervals of about 3 feet at the beginning, and they are withdrawn after 8 or 10 days' time. Into the holes which the stakes have left enough water is poured to saturate anew the ashes. At the end of two months, when the bones have become considerably softened, the heap should be thrown over, moistened, and allowed to ferment anew; and this process should be repeated at intervals, as often as may be needed. Five months in all, and perhaps three forkings over, will be sufficient to reduce the bones so completely that only some fragments will remain of the largest head and thigh bones. These will naturally be laid aside, to be thrown into the next heap that is made.

Field Experiments with Fermented Bone.

The following experiments by J. Lehmann relate to the fertilizing action of bone-meal that had been fermented with alkali. Grain was grown during four successive years, but the fertilizers were all applied at the beginning of the first year. Hence the crops of the later years indicate the powers of endurance both of the bone-meal and of the reinforcements that were added with it. In all the experiments, excepting the one where the material was converted to superphosphate, the bone-meal, after having been thoroughly mixed with the reinforcing fertilizer, was moistened with as much concentrated lye as was needed in order that the meal should ball when squeezed in the hand, and slowly fall asunder again after the pressure of the hand was removed. The mixture was then left to ferment during several days before it was worked into the soil.

The figures of the following table are given in pounds, and they relate to a German acre.

YIELD OF GRAIN.

Year.	Crop.	No Manure.	10 cwt. of the Bone-meal.	10 cwt. Bone-meal and 2 cwt. Sulphuric Acid.	10 cwt. Bone-meal and 4 cwt. Nitrate of Soda.	10 cwt. Bone-meal and 5 cwt. Sawdust.	10 cwt. Bone-meal and 5 cwt. 40 lb. Peruv. Guano.
1858	Rye	880	1,240	2,380	2,680	3,000	3,080
1859	Rye	1,980	2,420	2,620	2,440	2,640	3,040
1860	Oats	1,900	2,460	3,200	3,560	3,480	3,800
1861	Barley	1,840	2,360	2,360	2,160	2,176	2,280
Sum		6,600	8,480	10,560	10,840	11,296	12,200

STRAW AND CHAFF.

1858	Rye	5,700	6,780	7,780	6,680	7,400	7,240
1859	Rye	5,420	6,380	7,420	7,520	7,440	8,000
1860	Oats	2,980	3,420	4,100	4,360	4,200	4,560
1861	Barley	2,900	3,360	3,040	3,200	3,240	3,240
Sum		17,000	19,940	22,340	21,760	22,280	23,040

MONEY PROFIT FROM THE CROPS OF THE FOUR YEARS.

$108	$123	$153	$144	$171	$168

The influence of the fertilizers is plainly marked, both in respect to the production of grain and of straw. It will be noticed, also, that larger crops were obtained on adding active nitrogenous fertilizers. Even sawdust shows conspicuous merit as a cheap means of hastening the action of the bone. The first year happened to be very dry, and the effects of this drought are shown plainly in the small crops of rye on the unmanured land and on that which got nothing but bone meal.

Disintegration of Bones with Lime.

Efforts have been made in Germany to decompose bones by means of the alkali quick-lime instead of potash. For example, Walderdorff has recommended the following method. Ordinary bones which have been neither boiled nor broken are spread out in a layer six inches deep, and covered first with a layer of quick-lime of equal depth, and then with a layer of loam. Other similar layers are piled above the first series until the heap has been built up to a convenient size, when it is covered with a thick layer of earth. Holes are then pierced in the heap, and water poured in to slake the lime. As much lime is taken as will amount to about twice the bulk of the bones.

A heap of this sort which contained some 8,000 lb. of all sorts of bones remained very hot for eight weeks, and in active fermentation; the heat coming not only from the action of the water upon the lime, but from the action of the lime upon the bones. When the fermentation ceases, the bones are said to be found in a brittle, friable condition, and the heap is finally shovelled over in order to mix the materials.

Peters reported, some years since, that he obtained good results by composting bones with a mixture of quick-lime and sulphate of potash. The whole subject of reducing bones with quicklime and Stassfurt potash salts, notably the muriate of potash, deserves to be studied at the farm.

Phosphate of Lime of the Gelatine Makers.

In Europe, large quantities of bones are treated every year with muriatic acid for the purpose of obtaining their ossein, as a preliminary step in the manufacture of gelatine. In this case the earthy matter of the bones is actually dissolved out from the ossein by means of weak muriatic acid. The method is applied particularly to horn-piths, and to other bones which expose a large surface for the action of the acid, — notably to the thin waste slices of bone from which buttons have been cut.

To the clear solution of phosphate of lime in muriatic acid thus obtained, enough milk of lime is added to neutralize the acid and precipitate the phosphate of lime. This precipitate, which consists of bone-earth in the form of an exceedingly fine powder, might of course be applied to the land directly, as if it were bone-ash. According to Wolff, it contains on the average, as sold, 19.5% of phosphoric acid, about 28% of water, and 1.5% of nitrogen. But it is an interesting bit of evidence in favor of the use of superphosphates, that the precipitate in question is everywhere treated with sulphuric acid, and so converted into superphosphate before it is sent into commerce.

Enormous quantities of gelatine are made by this method in Europe at the alkali works where weak muriatic acid is a drug upon the manufacturer's hands, so that no small quantity of bone-earth is thus dissolved. But I found, some years ago, on visiting many chemical works in Europe, that everywhere in England, France, and Germany the reprecipitated bone-earth was converted into superphosphate as a matter of course before it was offered for sale, so thoroughly convinced were the European farmers of the value of soluble phosphoric acid.

Variable Composition of Superphosphates.

The simple fact that milk of lime is used to precipitate the bone-earth from its solution in muriatic acid, as above mentioned, would of itself be sufficient to suggest that the precipitate may vary considerably in composition, according as more or less of the lime milk is added. Hence, a certain liability to variation in the composition of superphosphates made from such material even.

But this point is as nothing in comparison with the impurity of many of the mineral phosphates from which most superphosphates are now made. In not a few localities there are found considerable quantities of impure phosphate of lime in the form of nodules or concretions, which were at one time called "coprolites," from a supposed resemblance to fossil dung. Occasionally, these nodules may contain as much as 80% of calcic phosphate, and at other times no more than 10%; 30, 40, 50, and 60% are common proportions. Samples of nodules from the sandstone of the Connecticut River, examined by the late Dr. Dana of Lowell, contained 40% of phosphates; and specimens from Canada have been found to contain 40 to 45%.

As found, however, in the form of the minerals apatite and phosphorite, the proportion of phosphate of lime in pure specimens may amount to 90%, or even more. Canadian apatite, as sent into commerce, contains some 80 to 86% of calcic phosphate. This mineral is very compact, however, and hard to grind, and is said to give off much fluorhydric acid when treated with oil of vitriol.

Inexhaustible beds of phosphorite occur in Spain and Portugal, and those in the province of Estramadura have long been famous. As obtained by the manufacturers of fertilizers, these phosphates contain some 70 to 85% of phosphate of lime, and they are esteemed because they are comparatively free from compounds of iron and alumina. Phosphate rock from Norway also contains 70 to 90% of calcic phosphate.

The Nassau phosphorit, which occurs in beds or nests, contains about 65% of phosphate of lime, or rather from 60 to 70%, though some samples contain as much as 80 or 90%. That from South Carolina is said to contain 57 to 60% as exported. It is easily acted upon by the acid, though rather hard to grind.

The better kinds of phosphatic guanos contain a great deal of phosphate of lime of a high degree of purity, that is easily acted upon by acids. They are consequently well fitted for making high-grade superphosphates. Baker Island guano, for example, contains some 65 to 85% of phosphate of lime (i. e. from 30 to nearly 40%

of P_2O_5), and hardly more than traces of iron and alumina. It seems to have been formed by the reaction of bird dung on moist coral sand. So too the phosphate from Howland's Island is said to be nearly as good as that from Baker's. Voelcker's analyses show 73 to 76%. An analogous product from Jarvis Island is also good, though it contains more gypsum than that from Baker's. It is said to contain some 45 to 52% of phosphate of lime.

On the other hand, the phosphatic guano from Sombrero, in the West Indies, though equally rich in phosphates with that from Jarvis Island, or even richer (for it may contain 70% or more), is less valuable, because it is contaminated with iron and alumina compounds. The Navassa phosphate also, from an island on the coast of Hayti, which has been a good deal used in this country, is much contaminated with the harmful alumina and iron compounds, although it is often rich in phosphates. It contains sometimes as much as 30 to 35% of phosphoric acid.

Redonda phosphate contains from 20 to 38% of phosphoric acid, or as much as would amount to from 42 to 84% of phosphate of lime, though in reality there is but little lime in this material, the phosphoric acid being combined with alumina.

Mejillones guano contains some 65 to 75% of phosphate of lime, and nearly one per cent of nitrogen, and that from Patagonia some 20 or 30% of phosphates and 4½% of nitrogen. Curaçoa guano contains 65 to 73% of phosphates.

Phosphatic Guanos.

It may be said of all the phosphatic guanos which have been formed from bird dung in rainy regions, that, although the nitrogen compounds and the potash of the original dung have been almost completely washed away, the phosphate itself is in a very different state from that in many of the rock phosphates proper, such as Canadian apatite, for example.

Much of the phosphoric acid in the phosphatic guanos could be dissolved tolerably easily by plant roots, and by carbonic-acid water in the soil. There can be no question that the phosphatic guanos, used as a fine powder, might be applied directly to the land in many situations. Most of them would probably do as good service as bone-black or bone-ash, or even better, on soils rich in humus, such as reclaimed bogs, or on cranberry beds or moist grass lands, or even for turnip and buckwheat fields. The powdered material might be incorporated with composts also, or with manure when the heaps are established, or when they are forked over.

The fact that the phosphatic guanos were tried on the large scale some years since, and found wanting when put in direct competition, on upland soils and for all kinds of crops, with farmyard manure, Peruvian guano, and superphosphates made from fresh bones, should not in the least deter the intelligent farmer from using them now in conjunction with other kinds of fertilizers, and in those particular positions which are suited to their character and to their real power.

It has repeatedly been proved, by experiments, that plant roots that are abundantly supplied with nitrogenous and potassic food can readily obtain phosphoric acid from powdered phosphatic guano, and even from powdered rock phosphates; and several observers have noticed that many of the natural phosphates are attacked to an appreciable extent in compost heaps.

Field Experiments with Rock Phosphates.

Some experiments by Voelcker on oats and peas may be cited as illustrating the value of finely ground natural phosphates, even on rich soils.

EXPERIMENTS WITH OATS ON MODERATELY HEAVY LAND.

Fertilizers on Acre.	Crop from Acre. Grain. Bushels.	Straw. Tons.
6½ cwt. ground coprolites	65	1⅜
5 cwt. coprolites treated with sulphuric acid	72½	2
10 cwt. ground Redonda phosphate	78¾	2
8½ cwt. bone-meal with sulphuric acid	61⅛	2
4½ cwt. precipitated phosphate	66	1 9/10
No manure	60	1⅝
3 cwt. raw bone-meal	61⅛	1⅛
20 tons of dung	70⅜	2 1/10
10 tons dung and 5 cwt. coprolites with sulphuric acid	67	2
10 tons dung and 6½ cwt. ground coprolites	62¾	2
5 tons of chalk	72	2¼
3 cwt. coprolites with sulphuric acid and 2½ cwt. Peruvian guano	64¾	2

EXPERIMENTS WITH PEAS ON LIGHT LAND.

No manure	39	2¼
5 cwt. ground coprolites	42	2¼
5 cwt. ground coprolites treated with sulphuric acid	44½	3
5 cwt. Redonda phosphate	43½	2½
4 cwt. precipitated phosphate	40½	2½
3 cwt. raw bone-meal	43½	2¼
3 cwt. bone-meal treated with sulphuric acid	42¾	2½
3 cwt. coprolites treated with sulphuric acid and 2½ cwt. Peruvian guano	43	2½

Solubility of Phosphates.

The solubility of pure precipitated terbasic phosphate of lime in carbonic-acid water, as determined by Warington, is 1 part of the phosphate in 1,789 parts of the liquid at about 50° F. and a mean barometric pressure of 29.535 inches. In one instance only did he obtain a rate of solubility as high as 1 in 1,540. He states that the solution of tricalcic phosphate in carbonic-acid water has a slight acid reaction.

Earlier and less elaborate experiments by Bischof gave the solubility as 1 part of the moist precipitated phosphate in 1,102 parts of carbonic-acid water, and Lassaigne gave it as 1 in 1,333 parts of carbonic-acid water, at 50° F. and the ordinary pressure of the air.

Other experiments by Warington are given in the following table.

EXPERIMENTS ON MOIST PRECIPITATED TRICALCIC PHOSPHATE.

Materials tested.	Solvent employed.	Barometic Pressure in Inches.	° F.	Parts Liquid to 1 Part Phosphate.
Tricalcic phosphate, pure precipitated	Boiled water	...	44.5	89,449
The same	1% chloride of ammonium in boiled water	...	50.0	19,629
The same	10% chloride of ammonium in boiled water	...	62.5	4,325
The same	Water saturated with carbonic acid	29.535	50.0	1,789
The same	1% chloride of ammonium in water saturated with carbonic acid	29,348	53.5	1,352
Same plus carbonate of lime	Water saturated with carbonic acid	29.776	69.8	42,314
Same as above	1% chloride of ammonium in water saturated with carbonic acid	29.378	60.8	18,552
Carbonate of lime alone	Water saturated with carbonic acid	29.463	70.0	1,016
The same	1% chloride of ammonium in water saturated with carbonic acid	29.425	55.5	950

The phosphates which occur in nature are all much less soluble in carbonic-acid water and other solvents than is the pure precipitated phosphate, as prepared in the laboratory. Thus, according to Warington, 1 part of the phosphate of lime in bone-ash dissolves in 6,788 parts of water saturated with carbonic acid. He found that

the magnesium phosphate of the bone dissolved before the calcic phosphate; and that, in general, more phosphate is dissolved by the first portions of the solvent that are applied to the bone-ash than by the succeeding portions.

According to Voelcker, 1 part of recently precipitated and still moist terphosphate of magnesia dissolves in 4,900 parts of water, while 1 part of terphosphate of lime in a similar fresh state dissolves in 12,610 parts of water. After the precipitates have been dried and ignited they dissolve in 10,000 and 31,847 parts of water respectively.

In saline solutions that contained one per cent of the salt, one part of terphosphate of lime dissolved as follows, viz.:

In 3,220 parts of a solution of chloride of ammonium.				
In 6,200	"	"	"	carbonate of ammonium.
In 15,800	"	"	"	chloride of sodium.
In 10,200	"	"	"	nitrate of soda.

After digestion in water for a week, the following quantities of terphosphate of lime were found dissolved in 100 litres of the liquid obtained from

Pure bone ash (from the very hard shin-bone of a horse)	0.168	grm.
American bone ash	0.268	"
Peruvian guano	0.359	"
Kooria Mooria guano	0.188	"
Sombrero phosphatic guano	0.120	"
Monk's Island phosphatic guano	0.142	"
Suffolk County coprolites	0.090	"
Cambridgeshire coprolites	0.085	"
Estramadura phosphate	0.014	"
Norwegian apatite	0.063	"

Some of the same kinds of phosphates digested with 1% solutions of ammonium salts gave the following results. The figures represent the number of grams of terphosphate of lime that were contained in 100 litres of the solutions.

Pure bone-ash with chloride of ammonium	0.445
American bone-ash with chloride of ammonium (3 days' digestion)	0.137
The same (12 days' digestion)	0.536
Cambridge coprolites	0.216
The same with carbonate of ammonia	0.228
Suffolk coprolites	0.249
The same with chloride of ammonium	0.160

According to Fleischer, 1,000 parts of water at the ordinary temperature dissolve 0.0563 part of phosphoric acid from pure precipi-

tated diphosphate of lime. He states that the diphosphate dissolves as such both in water and in carbonic acid water, its solubility in the latter being much larger than in pure water. In presence of sodium bicarbonate the solubility of the diphosphate is greater than in mere water, though the second molecule of carbonic acid in the sodium salt does not dissolve so much of the phosphate as a molecule of free carbonic acid would. The presence of lime salts or chloride of sodium, or of the matters which water can extract from some moor earths, hinders the solubility of the diphosphate in water.

When bone-meal is treated with water, much more carbonate of lime than of phosphate of lime goes into solution. Moreover, fine bone-meal gives up more phosphoric acid to water and to carbonic-acid water than coarse meal does, and steamed meal more than raw meal of the same degree of fineness.

Water and carbonic-acid water dissolve out from crude Mejillones guano no inconsiderable quantity of phosphoric acid, because of the presence in this guano of diphosphate of lime and phosphate of magnesia.

No appreciable quantity of phosphoric acid was dissolved from powdered Lahn phosphorite by water, while from another phosphorite, from Grosshütten, water dissolved considerable quantities of it, although the material was largely contaminated with carbonate of lime.

From precipitated ferric phosphate water dissolved an appreciable quantity of phosphoric acid, apparently with decomposition of the precipitate, but from precipitated phosphate of alumina much less phosphoric acid was dissolved by water.

According to Pierre, 1 part of ferric phosphate dissolves in 12,500 parts of carbonic-acid water that contains rather more than one volume of the gas, while for dissolving 1 part of ferrous phosphate no more than 1,000 parts of the carbonic-acid water are needed. When the carbonic-acid water was mixed with $\frac{1}{100}$ part of ordinary acetic acid, 560 parts of the mixture dissolved one part of ferrous phosphate. But when 9% of a concentrated solution of acetate of ammonia was added to the carbonic-acid water, then 1,666 parts of the liquid were needed in order to dissolve 1 part of the ferrous phosphate.

According to Nessler, the following amounts of phosphoric acid were dissolved out by 600 cc. carbonic-acid water in one day from 100 grams of the materials enumerated :—

From precipitated terphosphate of lime that was still moist . .	0.228[1] grm.
From precipitated terphosphate of lime that had been dried . .	0.308 "
From precipitated terphosphate of lime that had been ignited .	0.428[1] "
From finely powdered Sombrero phosphate	0.000 "

On adding 2 grm. of ammonium carbonate to the carbonic-acid water, 0.64 grm. of phosphoric acid was dissolved from the moist precipitate.

Karmrodt caused carbonic-acid gas to pass during 5 or 6 weeks through layers of coarsely powdered phosphates that were kept moist by drops of water which fell at intervals. He noticed that more lime was dissolved out than is contained in terphosphate of lime. At first, less phosphoric acid went into solution than was the case after the action of the carbonic acid had been longer continued.

From a sample of yellowish gray phosphorite that contained 32% of phosphoric acid, 1 part of phosphoric acid was dissolved by 8,300 parts of the carbonic-acid water.

From a sample of phosphorite, very red from the presence of oxide of iron, that contained 26% of phosphoric acid, one part of the phosphoric acid dissolved in 10,400 parts of the carbonic-acid water.

From bone-ash, with 34% of phosphoric acid, 1 part of the latter dissolved in 4,380 parts of the carbonic-acid water; and from raw bone-meal, with 20½% of phosphoric acid, 1 part of the acid dissolved in 5,267 parts of the carbonic-acid water. In the time specified there was dissolved:

	Per Cent of the Material.	Per Cent of the Phosphoric Acid in the Material.
From the 1st phosphorite	3.06	9.57
From the 2d phosphorite	2.39	9.20
From the bone-ash	5.49	16.13
From the bone-meal	4.63	22.60

From the bone-meals phosphate of magnesia dissolved in the carbonic-acid water before the phosphate of lime.

To test the comparative solubility of various phosphates in water and in carbonic-acid water, Bretschneider charged large bottles with the phosphates, covered the latter with the solvent, and shook the mixtures frequently at 64° F. during 24 hours. The carbonic-acid water was not quite saturated, but was $\frac{87}{100}$ of the full strength. The first column of figures in the following table gives the number of parts of water, and the second column the number of parts of

[1] These figures should probably be transposed.

carbonic-acid water, by which one part of phosphoric acid was dissolved in the several instances.

	Parts of Water.	Parts of Carbonic-acid Water.
Precipitated terphosphate of lime, fresh .	87,832	13,181
" " " ignited	159,532	13,324
Precipitated diphosphate of lime, fresh .	29,350	8,916
Phosphate of magnesia and ammonia . .	21,957	1,969
Ferric phosphate, freshly precipitated .	160,625	146,570
" " ignited	732,958	732,958
Finely powdered bone-black		249,480

According to Moser, one part of the phosphoric acid in finely powdered Mejillones guano dissolved in 24 hours' time in 55,800 parts of pure water, and in 13,084 parts of water that was saturated with carbonic acid. In another trial where carbonic-acid gas was made to pass during an hour each day for ten days through a mixture of water and the powdered mineral, one part of phosphoric acid dissolved in 8,542 parts of the water.

Williams suspended several powdered phosphates in water through which a current of carbonic acid-gas was made to flow during fifty hours at a temperature of 60° to 70° F. His results are as follows.

One part of the calcic phosphate ($3\,CaO, P_2O_5$) in Canadian apatite dissolved in	222,222	parts of the CO_2 water.
In same, very finely ground	140,840	" " "
In fine raw bone-meal	5,698	" " "
In bone-ash	8,029	" " "
In South Carolina phosphate	6,983	" " "
" " " finely powdered	6,544	" " "
In Orchilla phosphatic guano	8,009	" " "

Bischof had stated previously that 1 part of apatite dissolves in 393,000 parts of water saturated with carbonic acid, 1 part of fresh shavings of ox-bone in 4,610 parts, and 1 part of precipitated phosphate of lime in 1,102 parts (Lassaigne says 1,333 parts).

Dietrich and Koenig acted upon various phosphates with carbonic-acid water applied in such manner that the minerals were soaked in a half-saturated solution of it for 48 hours, and the residue from this treatment was digested in saturated carbonic-acid water for 12 weeks.

Material.	Per cent of Phosp. Acid contained in the Material.	After 48 Hours' action of ½ Saturated CO_2 Water, 1 Part Phosp. Acid dissolved in Parts of the Liquid.	After 12 Weeks with Saturated CO_2 Water, 1 Part P_2O_5 dissolved in Parts of the Liquid.
Estramadura phosphorite . .	37.20	90,900	90,900
Lahn phosphorite	14.80	60,100	60,100
Same	34.32	53,000	39,000
Sombrero phosp. guano . . .	38.81	48,000	48,000
Baker Island guano	41.74	19,000	8,330
Peruvian guano	13.70	2,440	1,230
Raw bone-meal	16.63	18,800	5,980
Steamed bone-meal	21.79	21,100	5,630
Bone-ash	37.57	25,250	7,350
Precipitated terphosphate of lime (ignited)	39.60	13,900	4,250
Ditto, dried at 212° F. . . .	42.99	13,500	3,630
Precipitated diphosphate of lime, sample No. I. . . .	46.45	5,430	2,250
Ditto, sample No. II. . . .	41.83	5,480	2,440
Ditto, sample No. III. . . .	41.92	6,130	5,900

The most remarkable fact brought out by this series of observations is the ready solubility of the precipitated diphosphate of lime in carbonic-acid water. Excepting Peruvian guano, none of the other materials were anything like as soluble.

Many experiments have been made also to determine the solubility of phosphates in weak acetic acid. Dietrich and Koenig used a 10% solution of the acid, and allowed it to act upon the minerals during 24 hours, at the end of which time a sample of the liquid was drawn off for analysis, while the remainder was left to digest during 12 weeks. The results of these trials are given in the following table. The composition of the materials has been given above in the table relating to carbonic acid.

	1 Litre of the Dilute Acid dissolved in 24 Hours grm. of Phosp. Acid.	1 Litre of the Dilute Acid dissolved in 12 Weeks grm. of Phosp. Acid.	Percentage of the Phosp. Acid in the Material that was dissolved.
Estramadura phosphorite . .	0.260	0.317	8.5
Lahn phosphorite, inferior .	0.260	0.336	22.7
Same, better	0.400	0.587	16.8
Sombrero guano	1.122	2.170	56.0
Baker Island guano . . .	1.177	1.865	44.7
Peruvian guano	1.122	2.875	100.0
Raw bone-meal	1.392	1.632	98.0
Steamed bone-meal	1.936	3.859	100.0
Bone-ash	1.884	2.869	76.0
Precipitated terphosphate of lime dried at 212° F. . .	3.232	. . .	100.0
Same, ignited	2.489	3.718	86.0
Precipitated diphosphate of lime, No. I.	3.848	. . .	100.0
Same, No. II.	6.265[1]	. . .	100.0
Same, No. III.	3.997	. . .	100.0

Krocker caused the finely powdered materials to be digested for 24 hours, at a temperature of 68° F., in dilute acetic acid that contained 12½% of the anhydrous acid. It was found that there had been dissolved by 1,000 parts of the solvent, from

Lahn phosphate rock	0.200	parts of	phosp.	acid.
Spanish phosphorite	0.200	"	"	"
Coprolites	0.310	"	"	"
Bone charcoal	0.310	"	"	"
Baker Island guano	2.660	"	"	"
Bone-meal	3.720	"	"	"
Precipitated phosphate of lime . . .	5.456	"	"	"
Same, slightly ignited	0.496	"	"	"
Lahn phosphorite with ammonium sulphate	0.370	"	"	"

Whence it appears that the solubility of precipitated phosphate of lime in the weak acid is 27 times larger, and that of bone-meal 18 or 19 times larger, than the solubility of the phosphate in some kinds of phosphate rock. The comparatively easy solubility in acids of a good phosphatic guano, like that from Baker's Island, is noteworthy.

In the experiments of Albert, 100 cc. of a mixture of 1 part acetic acid and 9 parts of water were made to act during three periods each of 4 days, upon one and the same gram of the finely powdered phosphatic material.

[1] An excess of the material was purposely added.

	In 1 Gram of the Phosphate there was of Phosp. Acid.	100 Grams of the Dilute Acid dissolved of the Phosp. Acid in 1st 4 Days.	2d 4 Days.	3d 4 Days.	Total dissolved by Dilute Acetic Acid in 12 Days.	
	grm.	grm.	grm.	grm.	grm.	%
Steamed bone-meal	0.232	0.229	....	....	0.229	99
Raw bone-meal	0.221	0.066	0.053	0.040	0.159	71
Peruvian guano	0.114	0.107	0.004	....	0.111	97
Baker Island guano	0.381	0.221	0.065	0.060	0.346	91
Bone charcoal	0.346	0.239	0.057	0.024	0.320	92
Precipitated phosphate of lime (hot dried)	0.339	0.304	0.002	....	0.306	90
Sombrero phosphatic guano	0.348	0.208	0.024	0.057	0.289	62
English coprolites	0.266	0.059	0.057	0.041	0.157	55
Estramadura phosphorite	0.387	0.056	0.025	0.016	0.097	25
Lahn phosphorite	0.259	0.025	0.008	0.003	0.036	14
Same, ignited	0.264	0.025	0.002	0.016	0.063	31
Same, boiled with potash lye	0.259	0.040	0.018	0.016	0.074	28
Navassa phosphatic guano	0.002	....	....	....	0.002	½
Leached superphosphate, made from phosphorite	0.088	0.043	0.009	0.008	0.060	68
The same	0.170	0.071	0.021	0.016	0.108	62

The ready solubility of the steamed bone-meal is noteworthy, and so is the hindrance to solution caused by the fat in the raw bone. In general the bone products dissolve more readily than the rocks, though the latter are still soluble enough to suggest the belief that appreciable quantities of them will dissolve in the course of time in the soil by the action of humic acid, carbonic acid, saline solutions, and plant roots. The easy solubility of the phosphate in guano and in Baker Island guano will be noticed.

Several investigators have tested the solubility of rock phosphate in humic acids, and in humate of ammonia, in the belief that the sparing solubility of phosphates in carbonic-acid water does not fully explain the good effects sometimes produced by such phosphates on peaty or moorland soils; and it has been shown that the humic acids have really a considerable solvent power for phosphates.

Dietrich mixed 50 grm. of finely powdered phosphorite (of 50%) with 50 grm. of powdered peat, and left the moistened mixture exposed to the air. He leached the mixture with water at intervals during ten months, with the result, that in 1,000 grm. of the

water used to leach the mixture there was dissolved 0.4688 grm. of phosphoric acid. But, as Dietrich has remarked, a dressing of phosphorite applied in field practice would find itself in presence of a much larger proportion of humus than was the case in his experiments. In another trial, where the peat was treated with a small amount of ammonia, rather less phosphoric acid was dissolved from the phosphorite, viz. .03769 grm. in 1,000 grm. of water.

Ten years after Dietrich, Fleischer, Koenig, and Kissling studied the question anew, and arrived at the conclusion that many kinds of peats and moor earths exert a more or less pronounced decomposing and solving action upon the so-called insoluble phosphates. It was found that pure precipitated diphosphate of lime was acted upon comparatively easily, and that precipitated terphosphate of lime also was strongly attacked, though very much less readily after it had been ignited than when fresh. Fine bone-meal was more readily acted upon than coarse, and bone-ash was considerably less soluble than bone-meal of the same degree of fineness. Precipitated phosphate of alumina was more strongly acted upon by the moor earth than precipitated phosphate of iron, and it was noticed that these phosphates could be decomposed by humate of lime in the moor earth with formation of phosphate of lime. Powdered phosphorites were less readily attacked than the substances above enumerated, though they were still acted upon to a noticeable degree.

Fleischer argues that there can hardly be a doubt that the free humic acids of the peat act to decompose the phosphates by combining with their lime or other base. He states that neither the precipitated nor the rock phosphates were much acted upon by moor earths which contained no free humic acids; but that, on the contrary, even the solvent action of mere water upon the phosphates was hindered by the presence of such earths, apparently because of the humate of lime which is contained in them.

Peats derived from moss, such as contain specially little inorganic matter, were found to act particularly forcibly upon the phosphates. Moreover, on adding lime or carbonate of lime to the moor earths which acted most freely upon the phosphates, their action ceased. So too, when moorland is cultivated, and the free humic acids in it are thereby neutralized to some extent, its power of dissolving the insoluble phosphates is materially lessened, and the more completely in proportion as the land has been more thoroughly manured. Nevertheless, it was found that even those moor-

lands which are most thoroughly cultivated still have the power to dissolve considerable quantities of the precipitated and rock phosphates. Moorland that has been burned for the sake of rendering it cultivable has its power of dissolving phosphates lessened, since considerable quantities of humic acids are destroyed by the combustion. For example, while 100 parts of air-dried peat derived from moss dissolved 0.4317 part of phosp. acid, 100 parts of peats taken from cultivated fields dissolved on the average no more than 0.1944 part of phosp. acid.

In general, the larger the quantity of the moor earth which was made to act upon a given weight of a phosphate, the more of the latter was decomposed, though the amount of phosp. acid dissolved was not strictly proportional to the amount of moor earth used, since that intimate contact between the earth and the phosphate which is needed to insure chemical action cannot be so well secured when large quantities of the earth are employed. As a rule, more points of contact between the phosphate and the earth can be secured, and more phosp. acid dissolved, by applying large quantities of phosphate to the land, although, in case the phosphate happens to be contaminated with carbonate of lime, the solvent action of the earth will be diminished in so far as humic acids are neutralized by the lime carbonate. In presence of sulphate of potash the solvent action of the moor earth upon phosphates was decidedly increased. Kainit also, muriate of potash, and even nitrate of soda, helped the solvent action somewhat; but gypsum, chloride of calcium, and especially carbonate of potash, hindered it very decidedly, apparently by neutralizing humic acids.

Koenig and Kiesow digested various phosphates with solutions of humate of ammonia that had been prepared with considerable care. 5 grm. quantities of phosphorite, for example, were warmed upon a water-bath, with varying quantities of the humate solution. The results were that 1,000 grm. of water dissolved the following amounts of phosphoric acid respectively from

	When digested with Humate of Ammonia.			
	50 cc.	100 cc.	200 cc.	300 cc.
	grm.	grm.	grm.	grm.
Powdered phosphorite that contained 31½% of phosphoric acid	0.051	0.064	0.071	....
Recently precipitated terphosphate of lime	0.199	0.222	0.234	0.323
Recently precipitated ferric phosphate	0.160	0.121	0.182	0.213
Recently precipitated aluminum phosphate	0.070	0.146	0.182	0.272

Pitsch also observed that solutions of humate of ammonia dissolve appreciable quantities of precipitated di- and tri-phosphate of lime, of precipitated ferric phosphate, and of Curaçao guano. He even compared the solvent action of the humate of ammonia with that of citrate of ammonia.

Chemical Analysis essential for discriminating between Superphosphates.

The statements given above as to the varying composition of superphosphates indicate clearly how important it must be for the farmer who may wish to buy a quantity of this fertilizer to know beforehand what the chemical composition of the samples submitted to him really is. As a matter of course, all the solid impurities and inert matters that are contained either in the bone or the rock phosphate used for the manufacture of a superphosphate are left admixed with the finished product, in addition to the gypsum which is necessarily formed by the action of the sulphuric acid. And beside these differences, dependent on the varying composition of the raw materials, the amount of soluble phosphoric acid in the superphosphate is apt to vary widely according as more or less care and skill have been devoted by the manufacturer to the treatment of the original substance. Even the earliest superphosphates made from bones were found to differ widely from one another in composition and in value according to the mode of manufacture.

It is, consequently, an absolute necessity that superphosphates must be bought and sold according to their contents of fertilizing matters, as shown by chemical analysis. There is simply no foreshadowing of a suggestion in the external appearance or character of the material as to what may be its real worth, or whether indeed it be worth anything. There can be no question that every ton of superphosphate sold in open market should be accompanied with a chemist's certificate of analysis, just as is done when soda-ash, bleaching-powder, and saltpetre are sold.

Moreover, it is the bounden duty of the manufacturers of superphosphate to employ competent analysts to keep the run of the article as manufactured, so that no samples inferior to the standard shall be thrown upon the market.

As matters now stand here in America, there is a wide range both as to quality and price, and although there have been very great improvements in recent years, there are even now none too many preparations that can be cordially commended. There have been

procurable, it is true, for many years, superphosphates made from bone-black that contained from 13 to 16% or more of soluble phosphoric acid, and these products were really excellent. They are still to be had, under the name of dissolved bone-black, or bone-black superphosphate, and there are likewise procurable nowadays other products of approved excellence; but for a long term of years the general rule in this country seems to have been to add a quantity of cheap fish scrap to a miserably prepared superphosphate, and to demand a high price for the mixture.

It has always been interesting to observe the absence in very many cases of any visible relation between the prices of these so-called superphosphates and the amounts of soluble phosphoric acid contained in them. There are numerous instances on record where products of extremely low value have been sold at specially high rates. It has frequently been noticeable withal, that some of the very best of the superphosphates, notably those made from bone-black, were offered to the farmers at exceptionally low prices. Apparently, the same conscience and good judgment that led the manufacturer to produce a superior article made him merciful in respect to his desire for pecuniary profit.

Even at the present time the lack of relation between value and price is sometimes very conspicuous. For example, two specimens of bone-black superphosphate, from different makers but of almost precisely the same composition, were analyzed at the New Haven station in 1884. They contained respectively

	A.	B.
Soluble phosphoric acid	17.13	17.29
Insoluble " "	0.09	0.11

But the price at which A was sold was \$34½ the ton, while the price of B was \$26.

It is absolutely necessary that the buyer shall have some kind of guaranty as to the chemical composition of superphosphates, and of late years it has become somewhat customary in this country to enact special laws for controlling the sale of fertilizers, and to appoint State inspectors of fertilizers to whom farmers may appeal. This system is still on trial, though open to grave criticism. One fundamental trouble is, that the matters to be inspected are too complex, the subject itself is too occult to be safely given over to a clique of political appointees. It is not here, as it is with the inspection of fish, or lime, or lumber, or potash, where the things to

be passed upon are so familiar that there could readily be found, in every community really interested in the subject, scores of people who would be perfectly competent to criticise the doings of the inspector; and, besides, a simpler and a much more equitable way of overcoming the difficulty lies ready at hand. If the large consumers of superphosphates and the reputable retailers of it would but refuse to buy except on the strength of a certificate from a responsible chemist; and if the agricultural societies would but pursue any dealer, or any so-called chemist, who plays their members false, a much healthier condition of things than now prevails might doubtless soon be brought about.

The best way to buy fertilizers is by large quantities, and in order to do that it will usually be necessary for a number of farmers to combine. It is not essential for the success of a club of this kind, that its members should be neighbors. All is, they must constitute for the moment one of their number "Agent and Treasurer," and let him deal with the manufacturers and sellers of fertilizers, and with the analysts also.

Each member of the club will submit a statement of the number of tons of fertilizers he wishes to buy, and the agent will make the necessary inquiries as to the best place to buy. In order to get this information, he will not only compare prices and samples, but will have analyses made of the samples that attract him.

He will buy large lots of the best manures he can find, that is to say, amounts equal to the sums of all the separate lots which the members of his club have asked for; and he will have the materials sent from the manufactory to the persons who have asked for them. Of course, there will have to be a clear understanding that the fertilizers shall have such and such composition. After they have come into the possession of the club, samples would naturally be drawn by lot, here and there, and subjected to analysis in order to make sure that the matters are what they purport to be, and that there may be no chance for fraud.

Some such system as this is not uncommon in England, and has indeed often been resorted to in this country for the purpose of bringing cargoes of lime, or ashes, or leached ashes, or grain, to a township, either by ship or by rail; but our farmers have hitherto known so little of chemistry that they have lacked that confidence in themselves and in one another which would be necessary if they were to deal in superphosphates successfully in this way.

Reverted Phosphate.

There are three different phosphates of lime familiarly known to agricultural chemists; viz. the tri-phosphate, such as is found in bones and in phosphatic minerals; the monophosphate, or soluble phosphate, or superphosphate, above described; and, intermediate between the two, there is a third kind, called biphosphate of lime, or dicalcic phosphate. The differences in composition between these three phosphates will appear from the following table.

Name.	Symbol.	Composition in Terms of Molecular Weights.				Per Cent.		
		Lime.	Water.	Phosp. Acid.	Total.	Lime.	Water.	Phosp. Acid.
Tri- or bone-phosphate	$3\,CaO,P_2O_5$	168	0	142	310	54.19	0.00	45.81
Bi- or di-phosphate	$2\,CaO,H_2O,P_2O_5$	112	18	142	272	41.18	6.61	52.21
Mono- or superphosphate	$CaO,2\,H_2O,P_2O_5$	56	36	142	234	23.93	15.39	60.68

One great trouble in respect to superphosphates is, that most of them cannot be kept for any great length of time without suffering deterioration. The soluble phosphoric acid contained in them is liable to "go back," as the term is, or to "revert," as is sometimes said, to an insoluble state.

The causes of this reversion are twofold. First, in making a superphosphate, it is hard to hit the precise point where the whole of the bone phosphate ($3\,CaO,P_2O_5$) has been converted to soluble phosphate ($CaO,\ 2\,H_2O,P_2O_5$) without using an excess of the sulphuric acid. But the presence of an excess of sulphuric acid is objectionable on many accounts, so that practically the manufacturers lean to the other alternative, and take care to use a little less sulphuric acid than would be needed to decompose every particle of the bone phosphate. Or, in cases where it is advisable to use an excess of the sulphuric acid at first, they are at pains to "dry" the product, as the term is, by adding to it bone-black, or bone-ash, or the precipitated phosphate of the gelatine makers. Thus it happens that the soluble phosphate, which has been formed at first by the action of the sulphuric acid, finds itself in presence of a quantity of undecomposed bone phosphate of lime, and in the course of time the two phosphates react upon each other, with formation of the intermediate compound, the so-called biphosphate of lime.

$$3\,CaO,P_2O_5 + CaO,\ 2\,H_2O,P_2O_5 = 2\ (2\,CaO,H_2O,P_2O_5).$$

That is to say, for every molecule of bone phosphate that has been left undecomposed, one molecule of the soluble phosphate is made to revert to an insoluble state.

In case the original materials are tolerably pure, as when bone-ash, or bone-black, or a first-rate rock phosphate, such as Baker Island guano, have been used for making the superphosphate, there is no inherent necessity that the reversion of the soluble phosphoric acid should amount to much. Of course there may be trouble if the manufacturer is careless or ignorant. If he fails to decompose the chief part of the bone phosphate which he has treated with sulphuric acid, the subsequent reversion will be large, and the depreciation in the value of the fertilizer will be serious. But if pains be taken to decompose the bone phosphate pretty thoroughly in the first instance, the subsequent reversion cannot be large. As was said just now, each molecule of the undecomposed bone phosphate can only decompose one molecule of the soluble phosphate, and when that has been done the action ceases. Manifestly, if but little bone phosphate has been left undecomposed by the manufacturer, there will be but little reversion of the soluble product. All this applies, however, only to the case where pure materials have been operated upon.

There is another cause of reversion, far less simple in theory and much more serious in its effects, which depends upon the presence of impurities, such as compounds of iron and alumina, in the natural phosphatic rocks, from which superphosphates are chiefly prepared nowadays. The difficulty here is that so long as the manufacturer uses the impure materials for making superphosphate in the ordinary way, he cannot avoid the reversion, no matter how careful or skilful he may be.

Just what the reactions are which are produced by the iron and alumina compounds has never been made out very clearly. But some idea of them may be gained from the following suggestions, which were thrown out by the English chemist Patterson. Suppose the sulphuric acid has dissolved a quantity of iron or alumina, then we may have the reaction

$$Fe_2O_3, 3\ SO_3, + CaO, 2\ H_2O, P_2O_5 = Fe_2O_3, P_2O_5 + CaO, SO_3 + 2\ (H_2O, SO_3),$$

and the free acid thus formed would proceed to dissolve more iron or alumina from the rock that had previously escaped decomposition, and the reaction here formulated would occur again and again. Here we have a cumulative process continually increasing the quan-

tity of insoluble Fe_2O_3,P_2O_5, and diminishing in the same proportion the soluble P_2O_5. Again, we might have simply

$$2\,Fe_2O_3 + 3\,(CaO,\,2\,H_2O,P_2O_5) = 2\,(Fe_2O_3,P_2O_5) + 3\,CaO,P_2O_5\,;$$

where three molecules of the soluble phosphoric acid are made to revert to the insoluble state at one blow.

In case the iron in the original rock were in the state of ferrous oxide, perhaps the following reaction might occur.

$$4\,(FeO,SO_3) + 2\,O + CaO,\,2\,H_2O,P_2O_5 + 3\,CaO,P_2O_5 = 2\,(Fe_2O_3,P_2O_5) + 4\,(CaO,SO_3).$$

In all these equations, except the last, alumina would serve as well as oxide of iron.

The bone phosphate of lime precipitated in the second of the foregoing equations would manifestly react in its turn upon a new molecule of the soluble phosphate in the manner described before.

But even supposing no biphosphate of lime ($2\,CaO,H_2O,P_2O_5$) were formed, but only Fe_2O_3,P_2O_5 or Al_2O_3,P_2O_5, these last would still represent reversion of soluble phosphoric acid, and reversion of the worst kind. For both the phosphates of iron and of alumina are notoriously insoluble, and are doubtless worth less when applied as fertilizers than biphosphate of lime is worth. There is a kind of phosphatic guano or phosphate rock from the West Indies, called Redonda phosphate, that contains naturally a large proportion of phosphate of alumina, but for many years this material was reputed to be worthless for agricultural purposes. No doubt it could be used in many situations, but it is none the less true that it is on the whole inferior to phosphate of lime.

Valuation of Reverted Phosphoric Acid.

It may here be said, that many disputes have arisen among chemists as to what value should be allowed for the reverted phosphoric acid in superphosphates, as compared with that of the soluble phosphoric acid and that of the original undecomposed bone phosphate.

It is a fact that the compound known as biphosphate of lime ($= 2\,CaO,H_2O,P_2O_5$), though wellnigh insoluble in water, is considerably more soluble in carbonic-acid water and in saline solutions than ordinary bone phosphate is. Hence it has been argued by some chemists, who have assumed in the first place that all the reverted phosphoric acid in a superphosphate is in the form of biphosphate of lime, that this substance ought not to be classed in the same category with the undecomposed bone phosphate, but that a somewhat higher value should be allowed for it.

The dealers in fertilizers generally stand by one another in maintaining that a price intermediate between the prices of soluble phosphoric acid and of insoluble bone phosphate should be allowed for the reverted phosphate. Thus, if soluble phosphoric acid be worth 13 cents per pound, and the acid in insoluble bone-ash phosphate be worth 5 cents, they claim that the reverted phosphoric acid is worth 8 or 9 cents per pound.

There are several methods, it should be said, of estimating the quantity of the reverted phosphoric acid in a superphosphate. One of the commonest of these methods is as follows. After the soluble phosphoric acid has been dissolved out from the superphosphate by means of cold water, the residue is treated with a solution of ammonium citrate, which dissolves the reverted phosphate; and, finally, the residue from the citrate leaching is treated with a strong acid, such as muriatic acid, in order to obtain that portion of the phosphoric acid which was neither soluble in water nor in the citrate of ammonium.

On looking at the matter, however, from the point of view of an instructed farmer, it is not easy to find any real and permanent basis for the assumption that the price paid for reverted phosphoric acid in a superphosphate should be much if any higher than the price ordinarily paid for insoluble phosphoric acid in the form of a good bone phosphate. It would be difficult, indeed, to find evidence that the price of 8 or 9 cents a pound, so often allowed for reverted phosphoric acid, has any justification whatsoever. There is but one criterion by which to appraise any chemical fertilizer, and that is by asking and answering the simple commercial question, What can this particular chemical substance be bought for in its cheapest form?

Now as for biphosphate of lime, that is to say, reverted phosphate of lime, this substance is prepared in Europe in a condition of almost absolute purity, and it could undoubtedly be imported either from England or from the Continent at small cost. In Europe, the price of this precipitated phosphate is controlled by the price of bone-ash, and the market value of a pound of phosphoric acid in the form of the precipitated phosphate is very nearly the same that it is when taken in the form of bone-ash. As was said before, a somewhat less pure form of precipitated phosphate of lime has, for many years past, been made in England, France, and Germany in no inconsiderable quantities, as a product incidental to the manufacture

of gelatine from bones; which is a branch of industry of whose importance, particularly to the wine-growing regions, few Americans have any just idea.

This precipitated phosphate of the gelatine makers is bought by the manufacturers of superphosphate as a substitute for bone-ash, and of course for an analogous price. When properly prepared, i. e. when freed from adhering acid and calcium chloride, this precipitated phosphate has undoubtedly an intrinsic agricultural value of its own. It might be applied directly to the soil, and would produce useful effects in many instances when so applied. It has in fact been tried in this way often enough in Europe, especially in the early days when fertilizers were less abundant than they are now, and the very fact that it is no longer bought by the farmers, but by superphosphate makers, shows that for general use it has been unable to compete with superphosphate of lime. The story is the same as that of bone-ash, bone-black, and the phosphatic guanos; each of these substances has been beaten in the race which they held long ago against the superphosphates.

It appears to have been proved conclusively by practical experience, that neither of these substances has so wide a range of applicability as the superphosphates. No one of them can be profitably applied to so many kinds of soils, and to so great a variety of crops, as the superphosphates; though, as has been repeatedly urged already, there are doubtless special cases and situations where one or another of them should be preferred to the more costly soluble product.

Precipitated Phosphate cheaper than Superphosphate.

So long as the prominent processes of chemical manufacturing industry remain as they are now, there will always be one fundamental reason why phosphoric acid in the form of precipitated (i. e. reverted) phosphate of lime must necessarily be cheaper than phosphoric acid in the form of superphosphate. For the dilute muriatic acid which collects as an incidental waste product at the great alkali works in Europe can readily be employed for preparing precipitated phosphate of lime from inferior rock phosphates which are so poor and impure that they could not economically be used directly for making superphosphate. As things are now, the precipitated phosphate could doubtless be profitably prepared in this way, and sold at a price but little if any higher than the cost of bone-ash.

Not only by the use of waste muriatic acid, but in several other ways, has it been proposed in Europe to prepare pure precipitated phosphate of lime in unlimited quantities from phosphatic rocks that are so impure that they cannot profitably be used directly for making superphosphates, and some of the methods suggested are so manifestly judicious that they must eventually be put in practice, even if they have not come into use already (as seems probable), so that there need be no difficulty in getting all the reverted phosphate any one may wish for, and at a very low price.

Means of making Reverted Phosphate.

Indeed, there are several ready methods by means of which any one could make the precipitated phosphate in case he should wish to do so for purposes of experiment or comparison. Thus, if a true superphosphate be mixed with slaked lime, or wood ashes, or leached ashes, or, better yet, with bone-black or bone ash, the soluble phosphoric acid will be made to revert, and the cost of each pound of the product will be small in case bone-black or bone-ash has been used as the precipitant.

Each man must decide for himself as to whether this method of procedure seems to him judicious. The superphosphate has been prepared with toil and trouble, and the proposition is, that it shall be destroyed without ever giving it opportunity to do the work for which it was specially fitted.

There is still another way of looking at the matter, viz.: The presence of either reverted or insoluble phosphoric acid in a superphosphate is, from the farmer's point of view, a mere impertinence. He has no use for either of these substances in this particular connection. They are merely in his way; they tend to interfere with his plans and calculations, and the selling of them thus admixed with soluble phosphoric acid is a practice that should be discouraged on many accounts.

Soluble phosphoric acid has its own peculiar part to play; the superphosphate is bought in order to get the soluble phosphoric acid that is contained in it, and the farmer has no use for any more insoluble phosphoric acid of any kind in this particular case than is supplied by the decomposition of the superphosphate in the soil.

But why is it, if the reverted or biphosphate of lime has some fertilizing power, that the presence of it in a superphosphate is undesirable? This point is well worthy of being considered in some detail. As has been said already, the evidence which has been

accumulated by chemical investigators indicates clearly that soluble compounds of phosphoric acid change to insoluble forms after they have soaked into the earth. The only reason why phosphoric acid is ever used in the soluble form is to insure its thorough distribution in the soil, so that, after the precipitation of the phosphate, the roots of plants may everywhere find a little of their phosphatic food.

It is just as easy to scatter a superphosphate upon the land in the first place, as has already been insisted, as it is to scatter bone-meal; and the same remark will apply to the processes of tillage by which the fertilizers are incorporated with the earth. So far as mere mechanical distribution goes, the farmer can do as well with bone-meal as with a superphosphate, and with a superphosphate as with bone-meal. It is after the mechanical distribution has been completed that the distribution which depends upon the solubility of the soluble phosphoric acid of the superphosphate comes into play; and that this supplementary chemical distribution is real and highly efficient has been proved by the experiments of several chemists.

It is plain that at the points where the solid particles of a superphosphate have actually touched the earth there will be some phosphoric acid left in any event. Some phosphoric acid will remain there in the insoluble form anyway, and the chances are that a good deal more will be left there than will be left in those other parts of the soil to which the acid has been carried only by way of solution.

At the points where the superphosphate fell upon the earth during its mechanical distribution, some phosphoric acid will be fixed — as it would be in any other part of the soil — by means of compounds of lime, iron, and alumina, with which the fertilizer comes into contact there; and since there is a larger quantity of phosphoric acid "in action" at these points than at any other place, the chances are that more of the acid will be fixed there than anywhere else.

But there is another and a very important matter to be considered in this connection, and that is the insoluble phosphoric acid originally present in the superphosphate. Since superphosphates are never absolutely pure, it must always happen that the soil wherever the particles of superphosphate fall will receive this amount of insoluble phosphoric acid also, in addition to what is fixed there by chemical action.

Now if, perchance, it should happen that a crop could put to profit more phosphoric acid at these points of mechanical contact

than it actually finds there, the inference is plain that this crop would undoubtedly have made good use of more phosphoric acid in all parts of the soil than it got; whence the final conclusion that the application of soluble phosphoric acid should have been larger.

But, on the other hand, if it were really desirable to increase the amount of phosphoric acid at the points of mechanical contact, i. e. at the surface of the soil, that could be done readily enough by mechanical means. This result could be accomplished by scattering, in addition to the true superphosphate, some bone-meal by itself, or some of the precipitated phosphate of the gelatine makers, that had been bought as such.

So far as this particular point is concerned, there would assuredly be no sense in the farmer's paying for the labor and skill, and other costs of manufacture, that must of necessity be expended in the preparation of a superphosphate, when the purpose he has in view can be accomplished by simpler means. Just so much of his purpose as can be accomplished by the simpler means should be so accomplished as a matter of course. If by using a certain proportion of bone-meal, or of the cheap precipitated phosphate, he can do away with the need of buying a large amount of superphosphate, well; but let him not delude himself with the thought that his purpose can be more cheaply accomplished by means of a poor reverted superphosphate.

In view of these considerations, it is not easy to escape the conviction that the precipitated phosphoric acid in a superphosphate is worth no more to the farmer than the same amount of the acid would be in the form of bone-meal, or of precipitated phosphate of lime, or even in that of spent bone-black from the sugar refiners.

Whether it is ever worth the farmer's while to use any precipitated or other insoluble form of phosphoric acid in connection with a superphosphate, is a question that can only be determined by long-continued intelligent observation and experimentation in the field.

It may be accepted as a fact, that the reverted phosphate is more readily soluble in carbonic-acid water than bone-ash is; and it is probably true that the reverted phosphate will be dissolved by the acids of plant roots that come in contact with it much more readily than powdered phosphate rock would be dissolved. But all this is no reason why the stuff should be bought at a high price in a superphosphate, when it can be procured on more reasonable terms elsewhere.

It may be freely admitted, also, that the question is still open as to whether chemically precipitated phosphate of lime may not be a more economical fertilizer than bone-meal, under some circumstances, as will appear directly. The question is one that needs to be carefully studied in any event. Professor Voelcker, in England, has seen reason to believe that the precipitated phosphate may be best in certain cases. That is to say, it may be better either than a superphosphate or than bone-meal. He urges as a fact of observation, that on sandy soils in England, and on all soils deficient in lime, heavy dressings of superphosphates that are rich in soluble phosphoric acid do not produce on root crops effects nearly so beneficial as are produced by them on soils that are somewhat strongly calcareous, or on soils that contain even a moderate proportion of lime.

When applied to root crops upon sandy soils greatly deficient in lime, a concentrated superphosphate may produce a smaller crop than a fertilizer containing only a quarter as much soluble phosphoric acid. The experience of light-land farmers in England, he says, in districts where the soil is deficient in lime, goes to prove that on land of that description it is better to apply to root crops bone-dust, or precipitated phosphate, or phosphatic manures containing no soluble phosphoric acid.

But, since the nitrogen in bone-meal is notoriously inefficient on dry light land, it may perhaps be true that upon such land the precipitated phosphate, used in conjunction with dung, will serve as good a fertilizing purpose as bone-meal, or possibly do better than bone-meal, while it would practically be preferable to bone-meal because its first cost is less. So too on reclaimed bogs and moorland, the precipitated phosphate may be preferable to any other kind.

Superphosphates help Young Crops.

As has been said, superphosphates are used especially for turnips abroad, where they are thought to have comparatively little significance for grain. It is said to be no uncommon thing for a dressing of 200 lb. of superphosphate to the acre to yield an increase of five tons of turnips. It is held in England, that, although superphosphates are useful for the turnip crop at every stage of its development, they are specially valuable at an early period of growth, when by urging on the young plants the fertilizer enables them to get beyond the reach of the turnip-fly. In this country, also, where superphosphates are used for cotton, corn, wheat, and potatoes, they are reputed to do their best service in hastening the growth of

young plants. This effect is said to be specially noteworthy in the case of Indian corn, though wheat and potatoes are thought to be somewhat benefited in the same way.

In respect to potatoes, it is often claimed that tubers grown by the use of superphosphate (and other artificial fertilizers) are fairer and smoother, i. e. less liable to be marred by scabs and scars, than those grown on land that has been dressed with farmyard manure. A natural inference is, that worms or insects harbored by the manure may attack and injure the potatoes; though, on the other hand, it is not impossible that the superphosphate when first applied may destroy all such pests that were lurking in the soil and free the land from them. The question is one of no little interest, for at the present time superphosphates are often applied to potatoes "in the hill," and if the second of the foregoing suppositions has no real foundation in fact, it may well be true that the much cheaper precipitated phosphate of lime, or even some of the better kinds of phosphatic guano in powder, might be substituted with advantage for this particular purpose, i. e. they might be used instead of the superphosphate for manuring potatoes in the hill.

Merit of thorough Dissemination.

Some recent experiments of Petermann and Wassage, which illustrate the importance of thoroughly incorporating some kinds of artificial fertilizers with the soil, enforce at the same time the peculiar merit of those fertilizers which, like nitrates, true superphosphates, and dung liquor, can disseminate themselves in the earth. The experiments were with sugar beets. Those of the year 1881 were on plots of 23 square metres, which were dressed with 2,300 grams of a mixture that contained 3.69% of nitrogen, as nitrate of soda, 6.39% of potash, and 6.21% of phosphoric acid soluble in citrate of ammonia (i. e. phosphoric acid in the form of reverted phosphate of lime). In 1881 the following crops were harvested:—

Treatment of Plot.	Kilos to the Hectare.	Increase of Crop. Kilos.	Per Cent.
No manure	17,657	. . . .	. . .
Manure raked in	22,950	4,933	27.9
" hoed in 4⅗ in. deep . . .	32,674	15,017	85.1
" spaded in 8⅗ in. deep . .	38,543	20,886	118.3

The crops of 1882 were as follows:—

No manure	21,772	. . . .	. . .
Manure raked in	22,453	681	3.1
" hoed in 4⅗ in. deep . . .	36,217	14,445	66.4
" spaded in 8⅗ in. deep . . .	39,030	17,258	79.3

The manure of 1882 consisted of dried blood, nitrate of soda, sulphate of ammonia, chloride of potassium, bone "superphosphate," so called, and precipitated phosphate. It was applied at the rate of 1,000 kilos to the hectare, and contained 2.05% organic nitrogen, 1.98% ammoniacal nitrogen, 1.52% nitrate nitrogen, 5.18% potash, and 8.94% phosphoric acid soluble in citrate.

The final trials of 1883 were on fields dressed with 500 kilos nitrate of soda (with 15.53% nitrogen) to the hectare and 650 kilos of "superphosphate" (with 14.51% of phosphoric acid soluble in citrate). The averages of the results were: —

	Roots to the Hectare, in Kilos.	Tops to the Hectare, in Kilos.
No manure	49,310	24,722
Manure harrowed in	58,547	31,625
" lightly spaded in	65,726	34,675
" spaded in deep	69,596	37,243
" strewn in the drills	61,392	38,795

Other trials showed that, when sown with the seed, the fertilizers tended to hinder germination and to injure the crop.

Very heavy dressings of superphosphate are not infrequently applied to turnips in England; as much, for example, as 5 to 7 cwt. to the acre. But when used in conjunction with farmyard manure, 3 or 4 cwt. of the fertilizer are there thought to be enough. In this country much smaller quantities than the foregoing have often been used, such, for example, as 150 or 200 lb. to the acre; though latterly larger quantities are not infrequently employed. 500 lb. of superphosphate and 15 to 25 bushels of wood ashes to the acre have been recommended for potatoes. The superphosphate is sown in the furrows, and is esteemed as giving potatoes that are comparatively free from scale, and less liable to rot than those dressed with barnyard manure.

According to Mr. Harris, superphosphate is sown quite generally on winter wheat in Western New York, and also on barley and oats in the spring, while its use is not so common there upon corn and potatoes. He is in doubt as to how much this difference in practice may depend upon the superphosphate's giving a more marked increase in the yield per acre with grain, or upon the fact that a given weight of increase of grain will sell for more money than the same weight of corn; but he inclines to the belief that one prominent reason for the difference may be that the cost of applying the fertilizer to the grain land is merely nominal, while it is by no means so easy to

apply it for the hill crops. The drill from which the grain is sown has an attachment for distributing the superphosphate at the same time as the grain. Though not actually mixed with the seeds, the fertilizer drops into the same tubes which deliver the seed, and is sown in the same drill mark, so that it is deposited where the roots of the young plants can readily find it; whereas, when corn and potatoes are planted in hills, the superphosphate has to be dropped into the hill by hand, and that at a very busy season.

The winter wheat is sown early in September at the rate of 1½ to 2½ bushels to the acre, together with about 200 lb. (say $3 worth) of the superphosphate, and if the fertilizer gives an increase of no more than five bushels of wheat to the acre, the farmer has usually good reason to be satisfied. Practically, the increase is said to be often much more than five bushels.

Here again, with wheat, it is thought that the superphosphate does good service by enabling the young crop to get a fair start, notably by promoting a vigorous growth of roots in early autumn, so that the plants are better able to find moisture and food than they would have been if less fully equipped, and better fitted to survive a hard winter. By thus saving a crop, which but for the fertilizer would have perished, a couple of hundred pounds of superphosphate may do an amount of good out of all proportion greater than the cost of the material. An impression gains ground withal, that the presence of good phosphates in the soil specially favors the fermentations which convert the inert nitrogen of humus into assimilable plant-food.

Phosphates occur in all Soils.

Although phosphoric acid is universally acknowleged to be one of the most important of manures, and, after nitrogen, and in some places potash, the one of which ordinary soils stand in greatest need, it must always be borne in mind that minute quantities of phosphates occur in almost every kind of rock, and consequently in the soils which result from the disintegration of the rocks.

This fact has been thoroughly established by pot experiments, in which plants were grown in soils composed of crushed rocks, the amount of phosphoric acid in the seed sown and in the plant harvested having been carefully determined in each case. The difference between the two quantities indicated, of course, the amount of phosphoric acid that had been taken from the rock. For that matter, the presence of traces of phosphoric acid in most rocks is

proved by the fact that wild plants are found growing everywhere in the soils which rocks have produced.

Professor Daubeny, who made many experiments upon this point, claimed that the experiments went to show that the older rocks contain a larger proportion of phosphates than those which are more recent. He suggested that it might perhaps be possible to judge *a priori* from the age of its rock whether a given soil stands in need of any addition of phosphoric acid.

But though thus widely diffused in nature, phosphoric acid is seldom abundant in any rock or soil. On the contrary, it must be regarded as one of the rarest kinds of plant-food. It is one of the ingredients of the soil which is most likely to be exhausted. As has been said, it is one of the most important components of barn-yard manure, of the dung of animals, and of many other commercial fertilizers beside those already described.

In rocks, the phosphoric acid is supposed to exist ordinarily in the form of phosphate of lime, though it sometimes occurs as phosphate of alumina or as phosphate of iron. As has been shown, the rock phosphate of lime is not absolutely insoluble in pure water; it is sparingly soluble in water charged with carbonic acid, and in water containing various neutral salts and organic matters. The carbonated and silicated alkalies, in particular, help to dissolve it. But, in the soil, the tendency always is that the phosphate of lime shall be changed to the even more insoluble phosphate of iron. Hence the solubility of the iron phosphate becomes a matter of no little interest. As has been stated already, Pierre showed long ago that phosphate of iron is appreciably soluble in carbonic-acid water; and, more recently, Peters has observed that reactions occur between the humus of the soil and ferric phosphate, which greatly promote the solution of the phosphate. While the ferric phosphate is reduced to ferrous phosphate by the humus, the latter is oxidized to the state of an acid product which acts as a solvent of the phosphates. Peters corroborates, moreover, the old observation, that the presence of neutral and alkaline salts in the soil promotes the solution of the phosphates.

It is to be remembered always, that since the phosphate of lime of bones dissolves comparatively easily in the earth, there is far less reason and profit in treating bones with acid than there is in acting upon the fossil phosphates.

At the worst, however, the phosphates are not so insoluble but

that quantities of them — small by comparison with the amount of water, but enormous in the aggregate — are constantly poured into the sea by every brook and river. In the ocean, they serve to nourish the aquatic plants and animals, and thence some small portion of them is recovered nowadays in the form of fish scrap, sea-weeds, and guano.

The sea is in fact an inexhaustible reservoir of phosphoric acid, from which any amount of manure may be drawn; the only question is how to reduce this manure to a transportable form. The preparation of guano by the sea-fowl was one way of reaching this result. The saving of fish refuse of various kinds is another way of utilizing the marine phosphoric acid, etc.; and this industry will undoubtedly assume large proportions when the natural guanos of the Pacific Ocean and the Caribbean Sea become exhausted. The use of sea-weeds in agriculture will be described in due course. It is not improbable, indeed, that the old practice of collecting and burning sea-weeds for the sake of the chemicals contained in them may be resumed one day in the interest of agriculture.

It has even been suggested in Europe that the so-called water-pest (Elodea Canadensis), the American weed of the English, may sometimes serve a useful purpose in brooks as a means of collecting phosphoric acid and other kinds of plant-food which would otherwise escape into the sea. The idea was that the weed might be collected and composted, or burned to ashes, according to circumstances. There has been talk at one time and another of the invention of mowing-machines wherewith to keep the Erie Canal clear of this water-weed; in which event its fertilizing constituents would doubtless be utilized by some farmers favorably situated for handling it.

It may here be said, that phosphoric acid is one of the things that tends most strongly to accumulate in the seeds of plants. It passes rapidly from the leaves and stem into or towards the fruit, through all the stages of growth from first to last.

Price of Phosphoric Acid.

A few words more need to be said concerning the price which has to be paid for phosphoric acid when bought in the form of one or another of the various kinds of phosphates above described. In this country the pound of useful phosphoric acid can generally be bought for the least money in the form of finely powdered phosphate rock, such as is sold under the trade name of "floats." In

many situations farmers would probably find an advantage in using this material, either directly upon soils surcharged with humus, or perhaps in composts, as well as by treating it with sulphuric acid in the manner described on a previous page.

In Boston, however, it has hitherto been more convenient to take the price of spent bone-black from the sugar refiners as a basis from which to compute the value of phosphoric acid in all its forms. For if this bone-black costs the farmer, say \$27 the ton, or 1⅓ cents per lb., each pound of the phosphoric acid contained in it may be rated at 4½ cents (very nearly), since the black contains nearly 30% of phosphoric acid.

The value of a pound of phosphoric acid in a superphosphate follows from the price that has to be paid for it in bone-black; for, as has been shown above, and as has been set forth in detail in the first volume of the Bussey Bulletin, it is easy for the farmer to make superphosphate for himself from bone-black. In Mr. Saltonstall's experience, as cited in the Bussey Bulletin, the pound of soluble phosphoric acid cost about 13 cents in 1873.

At the time this computation was made, it was found by actual trial that the pound of soluble phosphoric acid could be imported in small lots into Boston from either England or Germany, in the form of superphosphate, for the same price, viz. 13 cents. Latterly, the price has fallen to 10 cents.

A few years ago the cost of making a quantity of reverted phosphoric acid, for an experiment, was calculated as follows, taking the current price of bone-ash (\$24 the ton) and of bone-black superphosphate (\$32 the ton) as reported at the time in New York agricultural papers. The ash was assumed to contain 70% of bone phosphate, and the superphosphate to have 16% of soluble phosphoric acid. The reaction would occur between 155 lb. of $3\,CaO,P_2O_5$ (the molecular weight) costing \$1.94, and 117 lb. of $CaO, 2\,H_2O,P_2O_5$ costing \$7.02; and there would result 272 lb. of $2\,CaO,H_2O,P_2O_5$, i. e. twice the molecular weight, costing \$8.96.

But in the two molecules of the diphosphate of lime thus produced, there are 142 lb. of phosphoric acid; hence the pound of such phosphoric acid would cost \$0.06⅓. Assuming that the cost of labor in making 1,000 lb. of the material would be \$1, twenty-five cents must be added to the cost of the 272 lb. of diphosphate on this account, which will bring the price per pound up to 6½ cents. If the bone phosphate for this experiment had been bought in

the form of bone-black, the final cost of the diphosphate would have been a little more than 6¼ cents the pound; but if it had been bought in the form of ground phosphate rock, the cost would have been a little less.

Amounts of Phosphates sold off from Farms.

Highly interesting computations have been made by several German writers, notably Crusius and Heiden, as to the amounts of phosphoric acid that had been removed in crops, or added in the form of manure, in the cases of certain special farms where a careful system of bookkeeping permitted such calculations. Every agricultural student will do well to study in detail the examples given by Heiden in his book entitled "Statik des Landbaues." From lack of space, only rough outlines of one or two of the published examples can here be given.

Crusius tells of a farm that consisted of 670 Saxon acres of good arable loam overlying gravel, — by which it was well drained, — and 120 Saxon acres of good permanent meadow. The arable land was subjected to a rotation consisting of, 1. Rape, 2. Wheat, 3. Peas, 4. Rye, 5. Potatoes, 6. Barley, 7. Clover, 8. Rye, 9. Oats, 10. Turnips, 11. Rye, 12. Barley, 13. Clover, 14. Rye, 15. Oats, 16. White Clover, and was manured with farmyard manure four times during the 16 years, at the rate of 80 to 95 loads of 1,650 lb. each.

Accurate accounts were kept as to income and outgo of products during two full courses of the rotation, and when these results came to be stated in terms of five-year periods, it appeared that, although the total product of the farm had increased, grain and straw had not increased in the same proportion, for the proportion of straw was appreciably larger in the later years. This fact may readily be seen from the following table, which relates to the rye crop.

Years.	No. of Shocks of Sheaves.	100 Shocks of Sheaves gave Bushels of Grain when threshed.
1826–30	4,250	166
1831–35	5,379	170
1836–40	5,363	154
1841–45	6,857	140
1846–50	8,417	156
1851–55	7,082	121
1856–60	7,881	125

During the last 16 years, i. e. from 1845 to 1860, it appeared that 985.67 cwt. of phosphoric acid had been sold off the arable

land, and that only 408.33 cwt. of phosphoric acid were returned to it, so that the fields had been deprived of this constituent to the extent of 577.34 cwt., a fact which may perhaps explain the gradual diminution in the yield of grain.

Another interesting example is that of an estate at Waldau, where, as it appeared, both phosphoric acid and potash were continually added to the arable land in larger amounts than they were taken off, thanks to the fact that the estate comprised an unusually large proportion of permanent meadow. Beside patches of garden, woodland, etc., the estate consisted of 1,030 Morgen (1 M. = 0.631 acre) of arable, 773 M. of meadow, and 113 M. of pasture. The following table gives the outgo and income of phosphoric acid in German pounds for three years.

OUTGO OF P_2O_5.

	1860–61. lb.	1861–62. lb.	1862–63. lb.
From sale of crops	1,040	1,176	797
Through cattle: —			
A. Sale of animals	132	287	790
B. Sale of milk	87	115	137
C. Sale of wool	1	1	1
Sum of the outgo	1,260	1,579	1,725

INCOME OF P_2O_5.

	1860–61. lb.	1861–62. lb.	1862–63. lb.
Through purchase of fodder	898	463	468
Through hay from the meadow	2,685	2,757	1,790
Through purchase of fertilizers	1,405	2,181	...
Sum of the income	4,988	5,401	2,258
The income consequently exceeded the outgo to the extent of	3,728	3,822	533

Many similar computations might be cited from European experience. It is to be regretted that there are no American observations of this sort to discuss.

CHAPTER XI.

NITRATES.

It has long been known that the growth of plants is greatly promoted by the presence of nitrates in the soil; such as the nitrates of potash, lime, soda, and ammonia. Davy, near the beginning of this century, wrote as follows:—

"The vague ancient opinion of the use of nitre and of nitrous salts in vegetation seems to have been one of the principal speculative reasons for the defence of summer fallows. Nitrous salts are produced during the exposure of soils containing vegetable and animal remains, and in greatest abundance in hot weather, and it is probably by the combination of nitrogen from these remains with oxygen in the atmosphere that the acid is formed."

The justice of this view has been exemplified by some of the recent experiments of Lawes and Gilbert, in which from 34 to 55 lb. of nitrogen to the acre have been found in the form of nitrates at the end of summer in the uppermost 20 inches of soils that had been left to lie fallow during the spring and summer months. But even Davy was not fully informed as to the real value of nitrates, and it is only comparatively recently that their paramount importance has been established by observation and experiment. It is now known, that for many crops the nitrates are capable of supplying all the nitrogen which is needed; and that they are perhaps on the whole better adapted than any other one substance for supplying nitrogen to plants. The experiment of Boussingault, described on a previous page, well illustrates this point. In experiments made by way of water culture also, nitrates are relied upon as the best source of nitrogen. Generally speaking, they have been found to be more manageable, and at the same time more certain to promote the growth of plants, than ammonium salts or any other of the compounds of nitrogen.

Long-continued observation and many experiments have proved, that, beside the inorganic or ash ingredients of plants, there must always be some source of nitrogen in the soil in order that a crop may attain any considerable development. The growth of forests

and of all wild plants is really no exception to the rule. It is certain that there must be nitrogen in some shape in the soil, if there is to be abundant vegetation, and it is precisely in the case of wild plants that the influence of nitrates is on the whole most strongly marked. The nitrates, like other easily assimilable nitrogenized compounds, promote to a marked degree the growth of the leafy part of the plant, and the leaves of plants thus fed are characterized by a peculiarly intense green color.

Thus far, only nitrate of soda and nitrate of lime, more particularly the former, can be obtained cheaply enough to be used as manures. Large quantities of nitrate of soda are constantly imported from Peru, to be used both in agriculture and in the chemical arts. Crude nitrate of soda is found there incrusting the soil of a desert.

Nitre Beds.

Nitrate of lime, mixed with small quantities of the nitrates of potash, soda, and magnesia, might be prepared, if need were, by establishing saltpetre plantations like those which were formerly worked in Europe in the interest of gunpowder making. These "nitre beds" have already been alluded to as illustrating certain processes, the results of which may be detected in almost any good porous soil; and it has been suggested by a German chemist, that farmers might perhaps find their advantage in some cases, even nowadays, in working saltpetre beds up to the point of obtaining an earth highly charged with nitrate of lime. This earth could then be spread upon the land like any other compost. In any event, saltpetre plantations may be regarded as little more than compost heaps methodized and exaggerated. It is doubtless true, that in almost every very old compost heap more or less saltpetre may be generated. Perhaps one of the advantages of keeping manure until it is very old, and of forking it over repeatedly, may depend upon the fact that nitrates form in such heaps after active fermentation and putrefaction have ceased. But it is in the field itself that the farmer should particularly strive to encourage the formation of the lime nitrate.

Saltpetre Waste.

In addition to the above-mentioned nitrates, some slight allusion may be made to certain residues or waste products left in the process of refining East Indian saltpetre, which are occasionally sold as a fertilizer, and to old plastering taken from damp and dirty

houses. The saltpetre residues now in question are often obtainable at powder-mills as well as at some kinds of chemical works. They consist of varying quantities of the sulphates and chlorides of potassium and sodium, together with some nitrate of potash or of soda, say from 5 to 10%. There are doubtless a number of localities in this country where small quantities of the saltpetre waste may be obtained at cheap rates, since the material is of no use whatsoever excepting as a manure. It would be well, however, to have the substance analyzed before buying it, since its value depends almost wholly upon the nitrogen and the potash which are contained in it, and the proportion of these ingredients may sometimes be very small.

Old plastering, particularly that from the walls of damp and filthy rooms in cellars or basements, has long been esteemed valuable as a manure; though the European experience which applies to very old, very dirty, and very damp houses has comparatively little meaning in America. Scrapings from the limestone walls of cellars, particularly from those of barns and stables, are likewise valuable. In both cases it is nitrate of lime, which results from the long-continued contact of nitrogenous matters, air, and limestone, that gives special value to the plastering or to the porous stone. In the same category with these last should be placed the saltpetre earth of the Mammoth Cave, and of various other caves in the Middle and Western States. Wherever such nitrous earth can be obtained cheaply, it deserves the farmer's careful attention.

Nitrate of Soda.

Nitrate of soda, sometimes called Chili saltpetre, has been largely employed in Europe as a fertilizer, commonly in the form of a powder, which is applied at the rate of 100 or 150 lb. to the acre on land previously charged with farmyard manure. To insure the even distribution of quantities so small as these, it is well to mix the powdered nitrate with three or four parts of loam. The nitrate may either be strewn as a top-dressing when the grain is well above ground in the spring, or it may be harrowed in lightly just before sowing the seed in the spring. Experiments have shown that, if it were practically possible to apply this easily soluble substance by successive instalments, it would probably be profitable to do so. Experiments made by Voelcker in England, in different years, on top-dressing winter wheat, gave the following results. The soil was a calcareous clay. The fertilizers were mixed with ten parts of loam,

and strewn broadcast in late March or early April, when the wheat had fairly started.

Fertilizer on Acre.	Crop of 1859. Grain. Bushels of 60 lb.	Straw, etc. Long Tons.
1¾ cwt. nitrate of soda	38	1⅕
2½ cwt. Peruvian guano (15% N)	40$\frac{1}{10}$	1⅐
180 lb. nitrate of soda and 1½ cwt. common salt . .	40$\frac{6}{10}$	1⅕
4 tons chalk marl	27	⅘
No manure	27	⅘

	Crop of 1860. Grain.	Straw.	Crop of 1861. Grain.	Straw.
1½ cwt. of nitrate of soda	44⅙	1⅘	45⅓	1½
2 cwt. sulphate of ammonia	44	2	44⅓	1⅓
2½ cwt. Peruvian guano (of 15% N)	46$\frac{1}{10}$	1⅘	40½	1¼
1½ cwt. nitrate of soda, with 3 cwt. common salt	47½	2	45½	1½
3 cwt. common salt	35¼	1⅐	37^5	1$\frac{1}{10}$
32 bushels of soot	41⅔	1⅗	. .	. .
No manure	34	1⅓	31	1

	Crop of 1862. Grain.	Straw.
2 cwt. nitrate of soda	44½	1½
2 cwt. nitrate of soda with 4 cwt. common salt	44¾	1½
1½ cwt. nitrate of soda with 3 cwt. common salt	41½	1½
1 cwt. nitrate of soda with 2 cwt. common salt	38¾	1⅓
3 cwt. of common salt alone	38¾	1⅕
2 cwt. Peruvian guano (of 15% N)	43	1½
2 cwt. Peruvian guano with 2 cwt. common salt	48½	1⅓
No manure	29	1

Nitrate of soda may be used also to force root crops, as well as grain; and market gardeners in this country have found it advantageous occasionally to work into the soil of their onion beds enough nitrate of soda to give the crop a start whenever the slow growth or unhealthy appearance of the plants indicates that they stand in need of a stimulant. But nitrate of soda is not so well adapted as some other kinds of fertilizers for top-dressing mowing-fields that contain the true grasses, since it favors the growth of clover rather than of grass.

When used as a nitrogenous addition for reinforcing stable manure, a given weight of the nitrate has sometimes been estimated in England to act at least one quarter better than the same weight of the best Peruvian guano. Of course the best action of such a manure can only be had on rich soils, which contain all the other ingredients necessary for plants, and on soils moist enough to main-

tain prosperous crops. The soda saltpetre, like any other merely nitrogenous fertilizer, acts by exciting the plant to grow. It is not alone that the nitrate supplies the plant with food, but that it makes the plant vigorous enough to collect food for itself from the soil and the soil-water.

Pure nitrate of soda contains about 63% of nitric acid and 37% of soda. Theoretically, this comparatively large proportion of soda would seem to be an objection to the use of the salt, for plants have little or no need of sodium. It would seem, consequently, as if it would be much more appropriate to use as manure some substance like nitrate of potash, both ingredients of which are useful. But up to the present time the cost of nitrate of potash has been too great to admit of that salt's being used with much freedom in agriculture.

Nitrate of Potash sometimes used.

It is somewhat used of late for horticultural purposes, and in some special and peculiar cases in agriculture proper; but ordinarily the farmer contents himself with using mixtures of nitrate of soda and a potash salt, whereby the two constituents of nitrate of potash are brought to the land. No doubt it happens usually that some of the nitrate of soda applied to the land by itself soon changes there to nitrate of lime and nitrate of potash.

As met with in commerce, nitrate of soda is not quite pure, though usually very nearly so. It contains on the average some 94 or 95% of the pure salt, or say 15½% of nitrogen. Of late years a mixed potash soda nitrate has been carried to Europe from a particular locality in the South American desert whence nitrate of soda is derived. This mixed nitrate is of somewhat variable composition, but usually contains about 16% of potash and 15% of nitrogen. The proportion of nitrate of soda in it ranges from 55 to 63%, and that of nitrate of potash from 31 to 42%. The sum of the two nitrates ranges from 90 to 95%.

Nitrification.

During many years chemists were greatly perplexed in trying to explain the manner in which nitrates form in a saltpetre bed and in cultivated fields. For more than a century, indeed, experiments have been made continually, in the hope of discovering a satisfactory theory of nitrification, as the process is termed. Several of the facts of nitrification are familiar and conspicuous. For instance, it has long been known that, when animal and vegetable matters

containing nitrogen decay in the air, in contact with earth charged with limestone, or with wood ashes, the nitrates of lime and of potash are formed. On the other hand there are numerous localities, particularly in warm climates, where the soil is highly charged with nitrates. This remark is true, not only of the East Indies, but of Egypt, Poland, Hungary, and Italy. In each of these countries earths occur which are rich enough in saltpetre to pay the cost of working.

In all these places the nitrate of potash appears to have resulted from the decomposition of organic remains. In Egypt, for example, the nitrate comes from heaps of refuse thrown out by the earlier inhabitants, and in Poland from tumuli or hillocks which are really the remains of former habitations. At the time of the American Revolution, when enough gunpowder and saltpetre to attract attention were exported from Russia, it was reported that the inhabitants of the Ukraine were accustomed to spread wood ashes upon the sites of old encampments for the purpose of "attracting saltpetre," which could thereafter easily be separated.

Out of contact with carbonate of lime, or other alkali, a quantity of nitrate of ammonia is formed when nitrogenized matters decompose in the soil. This fact has been proved by careful experiments, but may be verified any day by testing the water of wells in crowded cities. Such water will almost always be found to contain nitrate of ammonia, often in large quantity, when the well happens to be near a leaky cesspool. The putrid contents of the cesspool ooze out into the soil, and are there brought into contact with enough air to convert a part of the ammonia in the filth into nitrate of ammonia, and since this substance is readily soluble in water it passes into the wells into which the water of the soil flows. Possibly, nitrates may thus be formed directly by the oxidation of organic matters, but it is certain that they are formed by the oxidation of ammonium compounds which have resulted from the quick putrefaction of organic matters.

Some chemists go so far as to assert that almost all the nitrates found in nature have been derived from the oxidation of ammonium compounds. Even in those cases where nitrates result from the oxidation of putrefied organic matters, it would be argued that ammonia is always formed in the first place, and that it constitutes an intermediate step in the reaction. Much evidence has been collected in support of this view, and it is probably true for most cases,

though it can hardly be said as yet that any one knows just what happens to nitrogenized organic matters when they are converted into nitrates.

Recent investigations have shown very clearly that the change of ammonia or of organic nitrogen compounds to nitrates in the earth is not a process of chemical oxidation pure and simple, such as might occur if the nitrogen compounds were to be treated in the laboratory with powerful oxidizing agents. It is not a plain chemical reaction, such as is obtained when caustic ammonia is boiled with potassium permanganate or subjected to the action of peroxide of hydrogen. It appears, on the contrary, that the intervention of a microscopic organized "ferment" is necessary in order that nitrates may be formed in the earth. Precisely how this ferment works is not yet known. All is, it is a minute microscopic plant, an organized ferment, like yeast, which under favoring conditions of warmth, moisture, and darkness lives upon the nitrogenized organic matters and upon ammonium compounds, as well as upon other things which it finds in the earth; and one result of its life is the formation of nitrites and nitrates. Not to force the analogy, it might be said that this production of nitrates by the agency of living things is somewhat akin to the production of carbonic acid by men and animals; for animals always live in localities that supply carbonaceous food and air, and it was noticed very early that carbon is in some way oxidized to carbonic acid in the places which animals frequent.

Tolerably high temperatures favor nitrification. Careful experiments have shown that nitrification is extremely feeble below 40° F., even if it does not wholly cease. The formation of nitrates is clearly appreciable, however, at temperatures of about 54°, and it increases rapidly as the temperature rises above that point. Just below 100° (at 98° or 99°), nitrification is at its maximum. Experimenters have obtained results in the course of a few days, when operating at 98°, that would in our climate have required months or years in ordinary outdoor experience. Above 100° the formation of nitrates decreases rapidly as the temperature rises. At 113° they form less readily than at 59°; at 122° only very small quantities are formed, and above 131° no trace of the formation of nitrates could be detected. Under favorable conditions, other things being equal, ten times as much saltpetre can be obtained at 99° as at 57°. As has been said, a proper proportion of moisture promotes nitrification, but drought is well-nigh fatal to the process. Indeed,

in absolutely dry air the ferment perishes, and mere dryness, as ordinarily understood, stops the action of the ferment as long as the condition of dryness lasts.

Naturally enough, all kinds of food necessary for the growth of the microscopic fungus which causes the formation of nitrates must be present in order to the success of the process. Phosphates, for example, are indispensable, and small quantities of the other ash ingredients of plants are needed, as well as an ammonium compound and carbonaceous matter. The presence of oxygen is essential, as has been well known to saltpetre boilers time out of mind. Pallas, writing in 1772 of his travels in Siberia, mentions as a fact familiarly known that nitre forms only near the surface of the soil. He cites an instance where, through ignorance of this circumstance, the discoverer of a saltpetre cave instead of contenting himself with leaching the surface soil, which was highly charged with nitre and yielded much profit, excavated the earth to a considerable depth, and consequently suffered great pecuniary loss.

Warington, on searching for the nitric ferment in loam at various depths, was no longer able to detect it with constancy and certainty at depths greater than 18 inches. Specimens of soil taken from depths less than 9 inches always caused nitrification in dilute sterilized urine, i. e. urine prepared for the experiment by destroying all living things which may have been contained in it. But soils taken from a greater depth than 9 inches often failed to excite the nitrification of the urine, and those from 18 inches seldom excited it. Only on one occasion in his experiments was nitrification excited by a soil taken from a depth of 3 feet.

It has been noticed that the nitric ferment does not prosper very well in a strong light. It appears to need darkness in order that it shall thrive. Hence, perhaps, one advantage in keeping manure in cellars and sheds. Probably it will be better to establish compost heaps under cover, or in the shade of trees even, than in the open.

The ferment is easily killed by poisons, notably by chloroform, saline matters, coal-tar, the spent lime of gas works, and by ferrous sulphate. Maercker reports that no nitrates could be detected in a moor earth that contained as much ferrous sulphate as would be equivalent to 1⅓% of ferrous oxide, and only very small quantities of nitrates could be found in other parts of the moor that contained about a quarter as much of the sulphate. But nitrates were abundant in a contiguous part of the moor that was free from the ferrous

salt. An acre of the moorland taken to the depth of 39½ inches contained, where no ferrous sulphate was present, 980 lb. N_2O_5 to the acre; where there was as much ferrous sulphate as would amount to 0.298% and 0.395% of ferrous oxide there were found 90 lb. and 147 lb. respectively of N_2O_5 to the acre, but where the ferrous sulphate amounted to 1.349% of ferrous oxide there was no nitrate whatsoever. As will be seen hereafter, the facts just stated teach that neither peat that contains copperas, nor unweathered gas lime, should be put into compost heaps, unless, indeed, as is possible, the two materials be made to correct one the other.

Putrefaction adverse to Nitrification.

It is to be observed that the formation of nitrates from organic matters can occur only during the slow decay of the organic matter, under circumstances which admit the presence of a large excess of oxygen. During rapid putrefaction or fermentation no nitrates are formed. On the contrary, any nitrates which might be present in the fermenting mass would soon be reduced and destroyed. Thus it has been noticed that, by the putrefaction of the white of egg, nitrate of potash that had been mixed with it was destroyed, and ammonia formed.

More than a hundred years ago a couple of French inspectors of saltpetre, Gavinet and Chevrand, called attention to the fact that the hog-pen is not of the nature of a nitre-bed; while, on the contrary, large quantities of saltpetre commonly form in stables where sheep or goats are kept. The hog, as they put it, reduces the earth and manure in his pen to the state of a thick moist paste, which is not at all favorable for the formation of nitrates; while in the sheep stalls the dung is spread about and kept moderately warm, and it is only occasionally moistened by the urine of the animals, in such wise that nitrates form there in large quantities.

At the period when these observations were made, i. e. at a time when nitre beds were still cultivated on the continent of Europe, an Italian named Lorgna stated most explicitly, that, "although quite beyond our limit of vision, it is none the less a fact that the act of nitrification is the last term of putrefaction." "It is well known," he says, "that putrescible matters do not become fit for the production of nitre unless they can undergo complete putrefaction, and it often happens that not an atom of nitre will form in a great mass of putrescible matters, not even when they have been kept for a long time, unless these matters have been divided and dispersed among porous

substances and distributed in small parcels, so that their fermentation may not be hindered, and that putrefaction may freely attain its highest point."

Carbonate of Lime aids Nitrification.

A certain slight degree of alkalinity in the soil has been found to favor the growth of the nitric ferment, and the presence of lime carbonate has long been reputed necessary in nitre beds. Touvenal, who experimented long ago with a variety of earths and chemicals, found that among them all chalk and pure carbonate of lime most constantly favored the formation of nitrates. He urged that it is to the presence of the lime carbonate that must be attributed the fact that nitrates are found more abundantly in calcareous soils than in those which have resulted from the decomposition of rocks other than limestones. In calcareous soils, he says, nitrates form even in the open air, though to a much smaller extent than in covered places, and in caves or huts or sheds that are inhabited.

Quicklime he found, on the contrary, to be much less useful than the carbonate for promoting the formation of nitre; and this difference was so strongly marked that he was led to question whether lime can ever by mere exposure to the air regain the whole amount of carbonic acid needed to neutralize it. This suggestion is one of some importance from the agricultural point of view, as teaching that air-slaked lime can perhaps never be a complete substitute for leached ashes, for example.

Touvenal's observation has been corroborated by experiments made by Boussingault, who found, on adding caustic lime to garden loam, that ammonia was set free, and that nitrification was hindered. It is now well known that, while a slight degree of alkalinity promotes nitrification, any large proportion of alkali should be avoided, since it does harm to the nitric ferment. Indeed, when much lime or other strong alkali is mixed with moist earth, rich in humus, processes of putrefactive fermentation set in, whereby nitrates are speedily reduced to ammonia, or even to free nitrogen gas.

Instead of the lime carbonate, very dilute solutions of carbonate of potash or carbonate of soda have been found to favor nitrification; but if such solutions are more concentrated than 2 or 3 thousandths they check the action of the ferment. So it is with carbonate of ammonia also. Solutions of it that are above a certain moderate strength will check nitrification as effectually as solutions of carbonate of soda. Warington has urged that the presence of

undue quantities of the ammonium carbonate, either that formed naturally, as when the urine of sheep ferments on dry land, or that added expressly as a test, will greatly hinder the process of nitrification. It is because of this action of concentrated carbonate of ammonia that urine does not nitrify, unless it has been diluted with water, or admixed with much earth. Herein also lies one justification of the practical rule that liquid manures should be applied to crops in a highly diluted condition. Warington argues that, if gypsum were mixed with strong solutions of urine, so that the carbonate of ammonia should be converted to sulphate, and the excessive alkalinity of the liquid be thus annulled, they could be nitrified easily enough.

In spite of the fact that the presence of carbonate of lime or even of wood ashes in a nitre bed may be highly important, practically speaking, it is still true that nitrates will form when neither of the stronger bases, such as lime, potash, or soda, are present, since in their absence a part of the ammonia remains unoxidized, and serves as a base to hold the nitric acid which is formed:

$$2\,NH_4 + 4\,O = NH_4NO_3 + H_2O.$$

But if lime or potash be present, then either nitrate of lime or nitrate of potash will be formed, as the case may be, and the whole of the ammonia, perhaps, may be changed to a nitrate. In any ordinary soil this result would be likely to occur, since nitrate of ammonia, on soaking into the soil, would be decomposed by compounds of lime, potash, and soda which the soil contains. It is to the absorption and change of gaseous carbonate of ammonia that the formation of saltpetre on cellar walls must be attributed in many cases, though a part of the nitre is doubtless derived from filth thrown against the wall, or sucked up into it from the earth by capillary attraction.

Reduction of Nitrates.

In view of the easy reduction of nitrates by putrefying organic matters, it is probable, as Kuhlman has urged, that nitrates are often deoxidized in the lower layers of soils that are not thoroughly aerated. Goppelsroeder has in fact observed that some soils rich in humus do readily reduce nitrates to nitrites, probably by the action of microdemes which reside in these soils, and there are reasons for believing that other forms of reduction may sometimes occur. Indeed, it would naturally be expected that deoxidation of nitrates would often occur in peat bogs, and similar situations, as it

does in manure heaps; and it is not unreasonable to suppose that in one and the same soil the conditions may be such that they will sometimes favor nitrification, and at other times reduction. Processes of reduction might prevail, for example, when a soil was water-soaked, and remained for some time in such condition that no air could enter its pores. Grouven has argued that soils which are fit for the cultivation of ordinary crops are usually too porous to permit the deoxidation of nitrates; but this view was enunciated before the influence of bacteria in effecting such deoxidation had been recognized, and, though perhaps true in general, it is probably subject to many exceptions and limitations.

It has often been observed, that soils which are exceptionally rich in organic matters may contain no nitrates, or as good as none. In specimens of the somewhat famous "black earth," from a fertile region in Russia, that contained respectively 7 and 9% of humus, Knop found only 0.0002 and 0.0006 part of nitric acid in 100 parts of earth. A remarkably rich alluvial soil from the banks of the Amazon, examined by Boussingault, contained no trace of nitrates, but as much as 0.05% of ammonia. This soil was composed of alternate layers of sand and decaying leaves, and contained some 40% of the latter.

From some preliminary trials, Kellner infers that nitrates are partially deoxidized in swampy rice fields where processes of reduction occur, and marsh-gas is formed. In consonance with the foregoing observations, it has been observed anew by Dehérain that, in the absence of oxygen, nitrates are readily destroyed, even at low temperatures, in soils that are rich in humus. The nitrates are reduced, as the chemical term is, and free nitrogen gas goes to waste. The destructive action evidently depends upon the presence of a microdeme, for it ceases when steps are taken to destroy all microscopic life, either by igniting the soil or by applying chloroform to it.

The bacterium, which causes butyric fermentation, appears to be competent to reduce nitrates under the conditions above stated; but the one which causes lactic fermentation is said not to have this power. Dehérain argues that nitrates formed in the upper layers of a soil may be reduced on passing to the lower layers, and so be lost for feeding plants. He finds, however, that the presence of lime, even in small quantities, prevents butyric fermentation in the soil.

Warington also has noticed that, when fresh soil is added to diluted urine, a destruction of the nitrates already present precedes the formation of new quantities of nitrates. The liquid always becomes turbid during this reduction of the nitrates, which is completed in a few days' time. It has been argued in this case that the bacteria which cause the reduction of nitrates multiply very rapidly for a time, and run their course before the bacterium which causes nitrification has become active.

As illustrating one practical consequence of the reduction of nitrates in the soil, the fact may be mentioned that in field experiments made at the Bussey Institution I have noticed several times that, in spite of the easy solubility of nitrate of soda, the fertilizing effect of this substance is not wholly exhausted in the first year of its application, but is seen to make itself felt somewhat in subsequent years. The same thing is shown in some of the field experiments of Lawes and Gilbert. I have myself been inclined to attribute this after effect to the fixation in the soil of some nitrogenous compound resulting from the reduction of the nitrate, or, possibly, to the formation of Knop's basic nitrates of iron and alumina. Lawes and Gilbert, on the contrary, consider that the nitrogen left in the roots and stubble of the crops that have been dressed with nitrates or with ammonium salts is the chief, if not the sole, remnant of the artificial fertilizer that abides in the soil for the benefit of subsequent crops. Their suggestion seems to me wholly inadequate to explain the appearances noticed by myself.

It is slow decay, such as is seen in very old manure or compost heaps, that have been turned over repeatedly, that favors the formation of nitrates. Thus much is known, and there is good reason to believe nowadays that the nitric ferment finds fit refuge and feeding grounds in the well-rotted manure. So too, manure which has been buried, not too deeply, in the soil, or even spread upon the surface of the ground, is fit to be changed to nitrates. In this sense, the practice of top-dressing the land with manure in the autumn, and leaving it uncovered during winter, is probably not ill-suited to warm climates like those of many parts of Continental Europe, for a part of the manure soaks into the porous earth, and the nitrogen of it is there converted into nitrates in due season. But this mild commendation can hardly apply to a custom, which prevails in some parts of New England, of spreading manure upon frozen ground there to be swept and leached by the winter rains.

To recapitulate. In order that nitrates may form in the soil, there must be free access of air, as well as a certain amount of humidity and warmth. The place had better be dark, and there must not be any excess of organic matter in a state of active putrefaction. If fresh manure is to be dealt with, it must be well incorporated with earthy matters.

Since saline matters are liable to kill the nitric ferment, it would not be wise to apply any very large quantity of common salt or muriate of potash, or superphosphate even, to places where nitrification is active. In this sense an application of gas lime, or of sulphocyanide of ammonium, or of mud charged with sulphuretted hydrogen, or with sulphides, or with ferrous sulphate, might sometimes do much harm to a field or to a compost heap.

Though not absolutely certain, as was said, it is still highly probable that nitrates are commonly formed from ammonium compounds, and not from the organized nitrogen compounds, i. e. not directly. It is known, at all events, that nitrites and nitrates can be formed from ammonium compounds by the action of the ferment, and there is much evidence which goes to show that the nitrogenized organic matter of the soil and of the compost heap is first changed to ammonia, — perhaps by direct chemical oxidation, — and that this ammonia is changed to a nitrate in its turn by the action of the ferment microdeme.

It has not yet been clearly made out what influence upon the formation of nitrates is exerted by substances in the soil, such as the oxides of iron (Fe_2O_3) and manganese (MnO_2), or sulphates of one kind or another (MSO_4), which are known to be capable of acting as oxidizing agents. The fact, familiar to chemists, that the black oxide of manganese, as found in nature, is apt to contain small amounts of nitrates, would of itself indicate that this compound may in some way promote the formation of nitrates; and Hünefeld and Reichart have reported experiments in which the presence of the higher oxides of manganese favored the formation of nitrites and nitrates.

The power of ferric oxide to convey oxygen from the air to organic matters is a familiar fact, seen in the holes around rusty nails in old shingles or boards, and in the wood of iron-fastened ships, and there are experiments of Knop and of Thenard which seem to show that ammonia itself may be oxidized by manganic and ferric oxides. The true explanation of the experiments of these chemists,

however, would seem to be, that certain nitrogenous matters in the soil were oxidized and changed by these agents to ammonia in the first place, and that this ammonia was changed to a nitrate in due course by ferment action.

As regards the sulphates, it has long been known that they act as oxidizing agents upon carbonaceous matters in the soil, and it is not wholly improbable that they can oxidize nitrogen compounds to ammonia as well. The odor of sulphuretted hydrogen which exhales from the mud of salt marshes and docks is due to the action of carbonic acid from the air or from fermenting organic matters upon sulphide of calcium which has been formed by the reduction of sulphate of lime in the sea-water by organic matter in the mud:

$$CaSO_4 + 2\,C = 2\,CO_2 + CaS.$$

The waters of many mineral springs are charged with sulphides, and with sulphuretted hydrogen, formed, no doubt, in a similar way, through the reduction of sulphates deep in the earth. So too a rotting pump-log or decaying leaves in a well of hard water, that is to say, of water charged with sulphate of lime, will soon convert the well into a veritable sulphur spring.

Richard has noticed recently that the nitrification of organic matters in sterile soil seemed to be promoted by the presence of the sulphates of potash, soda, and lime, but especially by the last, i. e. by gypsum; though in Wolff's experiments, where cubic foot portions of cow manure were left to rot during 15 months in a north room, a much smaller proportion of nitrates formed in the box which contained gypsum than in those which contained mere manure, or mixtures of manure and lime or charcoal. That ammonia may really be formed by the oxidizing action of sulphates on nitrogenized organic matters in the soil has been shown by the researches of Pagel and Oswald on moor earth.

It is to the oxidizing action of sulphates, which results of course in their own reduction, that is to be attributed the formation of the black earth which is found between the bricks of sidewalks and the stones of pavements in city streets, and particularly between the bricks or stones of the yards of city houses. So, too, the black color of the soil of privies and of stagnant swamps and ditches is often due to a similar cause, viz. the formation of black sulphide of iron through the reduction of sulphates in the soil. On being exposed to the air these black earths soon lose their deep color, for the ferrous sulphate is quickly oxidized, with formation of red oxide of iron.

The facility with which ammonia may be changed to nitrates within the soil by ferment action is illustrated by the following experiment of Knop. A quantity of sandy loam was exposed to the vapor of ammonia for three days. It was then spread out in a thin layer, moistened with water, and kept sheltered from rain until it had dried. Finally the amount of nitrates contained in it was determined. At the beginning of the experiment there were found 52 parts of nitric acid in 1,000,000 parts of the earth, but at the close there were 591 parts of nitric acid in every million parts of the earth, — more than eleven times as much as at the start. It was noticed in this experiment that the ammonia absorbed by the soil suffered no change so long as the soil was kept dry. It was only after the soil was moistened that the nitric ferment could act to oxidize the ammonia.

Doubtless a minute proportion of the nitrates which are formed in soils may be derived from ammonia that has come from the air; but the quantity of ammonia in the air is ordinarily so extremely small that there is no probability that any considerable amount of nitrates can be formed in this way. Possibly nitrogenous solid matters floating as dust in the air may be changed to nitrates also. It is a fact, at all events, that the outer layers of beds of porous marls and limestones have often been found to contain more or less nitrate of lime. A probable explanation of this phenomenon, however, is that the marls contained microscopic organisms such as can obtain nitrogen from the air.

Nitrates formed in Plants.

According to Berthelot and André, nitrate of potash is continually formed within the stalks and roots of plants, by the action of certain cells of the plant. The argument is, that these cells act in a manner analogous to those of the true ferment which causes nitrification in the earth; and that one prime purpose of the cells in the interior of plants is to promote processes of oxidation, such as give rise to the formation, not only of nitrates, but of compounds of carbonic, oxalic, tartaric, malic, citric, and other oxygenated acids. This action of the plant cells is similar to that of the cells in certain fruits, which, as Lechartier observed, can excite alcoholic fermentation much as if they were ordinary yeast.

It has been noticed that plants must be vigorous rather than sickly, in order that nitrification may occur in their stems, and that nitrates tend to disappear from the leaves of plants. That is to say,

in the leafy, green parts of the plant reducing actions prevail, instead of those which cause oxidation. It is there that carbonic acid from the air is reduced, with evolution of oxygen, and that nitrates also are transformed to amids and albuminoids.

Light, which favors the activity of the chlorophyl grains, appears to accelerate the decomposition of the nitrates, i. e. their transformation to amids; while darkness, as in the roots of plants, may be favorable for nitrification in the plant, as it is for the action of the ordinary nitric ferment in the soil. To show the analogy between the nitrifying plant cells and the ordinary nitric ferment, Berthelot and André leached a quantity of garden loam with water to remove nitrates, and heated the leached loam strongly in order to kill any organisms which might have been contained in it. They then put pieces of the stems of amaranth plants in the loam thus washed and sterilized, and it appeared that this vegetable matter was really capable of acting as a ferment; for after a while notable quantities of saltpetre were detected in the loam thus treated, although none was found in similar samples of loam to which none of the amaranth cells had been added.

Nitrates may be formed by purely Chemical Reactions.

Although the action of living cells, either those of the microscopic "ferment," or those within ordinary plants, seem to be essential for the conversion of ammonia or other nitrogen compounds to nitrates at the ordinary temperature of the air, it is to be remembered that it is not difficult to oxidize ammonia in the laboratory, so that it shall be converted into nitrous acid, nitric acid, and water. There are several ways of effecting this result, just as there are several ways of reducing nitrates to the condition of ammonia. For example, ammonia gas may be oxidized by passing a mixture of it and air over platinum sponge heated to 570° F., or even by thrusting a red-hot platinum wire into a mixture of the two gases:

$$2\,NH_3 + 7\,O = N_2O_4 + 3\,H_2O.$$

So, too, a vivid reaction is obtained on passing the vapor of chloride of ammonium and oxygen gas over hot platinum sponge:

$$2\,NH_4Cl + 7\,O = N_2O_4 + 3\,H_2O + 2\,HCl.$$

Conversely, nitric acid may be reduced by passing the vapor of it, together with hydrogen gas, over hot platinum sponge:

$$N_2O_5 + 16\,H = 2\,NH_3 + 5\,H_2O;$$

or by treating zinc or iron, or certain other metals, with a mixture of dilute nitric and chlorhydric acids:

$$HNO_3 + 8\,H = NH_3 + 3\,H_2O.$$

Beside all this, there is no question that, under favorable conditions, the free nitrogen and oxygen of the air may be made to combine, with formation of nitric acid. Minute quantities of nitric acid are no doubt made in this way incessantly in nature. It was thought a few years ago that ozone could combine with the free nitrogen of the air, and that nitric acid was continually being formed in this way. But it is now known that this supposition was erroneous, and that ozone has no such power, although it can oxidize both ammonia and nitrites, readily enough.

Formation of Nitrates in the Air.

It is true, however, that the nitrogen and oxygen of the air do unite when electric sparks pass through the air, and that nitrous acid is often formed also in processes of combustion; as when hydrogen, coal-gas, alcohol, or the like, is burned in the air. So too, when phosphorus slowly oxidizes in the air, and when metallic magnesium is burned, nitrites are formed. Though each of these instances is of great interest and importance, perhaps no one of them is more so than the fact that nitrites and nitrates are formed during the slow oxidation of phosphorus at the ordinary temperature of the air; for it is a fair inference that, if nitrites are thus formed during the slow oxidation of one substance, they may be during the oxidation of some other substances, perhaps of many other substances.

It is to be observed, that, in all the reactions here cited, the absolute amount of nitrites formed is extremely small in any one particular experiment. But the fact that any nitrite is thus formed is one of very great importance, not only because of its bearings upon the questions, How was it that the first plants in the world got any nitrogenized food? and, How is it that wild and uncultivated plants grow in the world as we find it now? — but because of the hope held out by these reactions that all the nitrates which an improved agriculture may need will be manufactured some day by technical processes analogous to these. Although nitrites of themselves appear not to be capable of supplying nitrogen to plants, they are so readily changed to nitrates that they must be regarded as valuable. By the action of ozone, for example, they are readily changed to nitrates, as happens to some of those formed during the slow oxidation of phosphorus.

It is plain on the face of the matter, that somewhere and somehow very considerable quantities of free nitrogen, such as is found in the air, must be converted into nitrates or ammonium compounds, or some other combination fit for feeding plants. If this were not so, the amount of vegetable and animal life on the globe would necessarily diminish from hour to hour, for it is known that, when plants and animals decay, some of the combined nitrogen that was contained in them is, so to say, lost to vegetation, since it escapes into the air as free nitrogen gas.

It is known that some nitrogen gas is lost from organic matters, both when they decay in presence of an excess of oxygen and when they putrefy under water, as in marshes and pools. Nitrogen is liberated also during the combustion or distillation of organic substances, even more readily than during their slow decay. For example, the nitrogen exhaled from volcanoes, and from many hot springs, is supposed to be derived not infrequently from the decomposition of organic matters deep in the earth. Bischof found, by experiment, that when wood burns most of the nitrogen that was contained in it separates in the free state. He found also, that the gases evolved during the progressive decomposition of bituminous coal are accompanied by free nitrogen, which had previously been contained in combination in the coal.

Inasmuch as there is no evidence of any general diminution of vegetable or animal life, it is not easy to believe that plants and animals, as they now exist upon the globe, can be wholly supported, either by the great reservoir of humus, i. e. of organic remains, which is found upon the earth, or by nitrates and ammonium compounds, resulting from the oxidation of this humus, that are contained in the waters on the earth. Hence the need of looking abroad for a new source of supply of combined nitrogen which shall compensate for the waste that is known to occur in processes of decay and putrefaction.

This question will be again referred to under the head of Vegetable Mould. But, geologically speaking, it may be accepted as proved, that some part of the constant new supply of combined nitrogen, so necessary for the maintenance of life of all kinds, must have come from the aforesaid union of nitrogen and oxygen, as an incident to electrical discharges and to processes of combustion. There can be no manner of doubt that some nitrogenous plant-food continues to be supplied to the world in this way. The only trouble

is, that the amount of nitrates, etc. brought to the land in a year is not large enough to compensate for the quantities carried off in minimum crops, or even for those that are leached out from the soil by the rain-water that drains away from it. It would be an enormous gain for agriculture if cheap and effective methods of producing such combination of nitrogen and oxygen at will could be discovered.

It has often been urged by political economists, that the rate of agricultural production is not likely ever to keep pace with the increase of population, since, as they say, no great or striking improvements in agriculture can be expected. No such improvement, they mean, as would double or treble the present rate of production. But in point of fact the discovery of a cheap and easy method of making nitrates from the air would enormously increase the food-producing capacity of the earth. Indeed, the probabilities are that the mere discovery of what appears to be the true theory of nitrification, viz. the ferment theory, just now alluded to, will ultimately greatly increase the production of food. Not only will farmers soon learn to make composts, and to apply manure in a more rational manner than was possible before, but they will take pains to foster and protect the ferment germs, and to sow them, as it were, and cultivate them in fit places.

Already the ferment theory of nitrification may be used to explain in a wholly unexpected way a very important tenet of modern agriculture. It has been observed, namely, as the result of wide experience, that while the grains and the grasses are specially benefited by nitrogenous manures, such as ammonium salts, nitrate of soda, and Peruvian guano, there are other crops, such as clover, turnips, and other roots, Indian corn even, that succeed best when treated with superphosphate of lime, or bone-meal, or wood ashes. It is consequently held as a general rule, that in systems of rotation the nitrogenous manures had better not be applied to the root or the clover crops. And this in spite of the fact that a crop of clover taken from a field which has received no nitrogenized manure may contain two or three times as much nitrogen as a wheat crop taken from the same kind of land after the addition of guano or nitrate of soda. It appears, in fact, that clover, far more than wheat, has the power to provide itself with nitrogen. Indeed, so much nitrogen is accumulated by the clover plant, that the mere roots and stubble of clover are esteemed a valuable manure for the wheat that follows clover in many courses of rotation.

In explanation of these peculiarities the idea suggests itself that the ground shaded by leafy crops, such as clover and turnips, may perhaps be a peculiarly fit and favorable nesting-place, either for the microdemes which cause nitrification, or for those which generate ammonia, and that by their means the inert nitrogen of the soil is rapidly changed to nitrates (or in some cases to ammonia). The grain crops, on the contrary, having no such power to foster the ferment microdemes, have to be supplied artificially with some kind of active nitrogenous food.

There is, moreover, another way of looking at the matter, for it is a fact that the grain crops and clover grow at different times and seasons. The really vigorous growth of the cereal grains occurs in spring and early summer; that is to say, at a time when the store of nitrates in the soil has been reduced to its lowest terms by the rains of autumn, winter, and early spring, and when only comparatively small quantities of nitrates are in process of formation because of the coolness of the soil. But a crop of clover, of roots, or of Indian corn grows most freely in midsummer. Such a crop not only finds as large an amount of nitrates in the soil to begin with as the cereals found, but it has continued access to the nitrates that are formed in the soil during the hot summer weather. It is on this account, doubtless, that Indian corn has been found to differ so much from the other grains in respect to the kinds of fertilizers it requires. American farmers have, as a rule, found no special advantage in giving their corn crops nitrates or ammonium salts, although these fertilizers are regarded almost as specifics for wheat and barley in countries where agriculture is somewhat advanced.

It has not yet been clearly made out what influence for the formation of nitrates may be exerted by the ozone and the peroxide of hydrogen which are contained in small amounts in atmospheric air. It is not probable that either of these substances occurs naturally in sufficient quantity at any one spot to destroy the ferment microdemes, while there is good reason to believe that they may act to form nitrates in some cases, either directly by oxidizing organic matters, or more probably, perhaps, by oxidizing organic matter to ammonia, which is afterwards changed to nitrates by the ferment. It is known, withal, that both ozone and peroxide of hydrogen can oxidize ammonia to nitrates.

Peroxide of hydrogen is often brought to the ground in appreciable quantities by summer showers, and the peculiarly rapid

formation of rust sometimes noticed on iron articles which have been wet by such rains, is probably due to the presence of this substance.

As for the ozone in the air, there is never very much of it in any one place. Indeed, the amount is exceedingly minute, amounting to no more perhaps than one part in several million parts of air. But taken in the aggregate, the amount of ozone is by no means small, and it is not improbable that it may have considerable influence in the formation of nitrates. It is known, for example, that ozone acts rapidly upon many kinds of organic matter. For the reactions of ozone have repeatedly been detected in the air on the windward side of manure heaps, when no trace of it was indicated in the air to leeward of the heap. It has often been noticed, also, that little or no ozone can be detected in the air of cities at times when it is abundant in the air of the neighboring country. Sometimes it is abundant on the windward side of a city, and as good as absent from the air immediately to leeward; the inference being that it has been consumed in oxidizing organic matters. Interesting observations upon this point have been made by Dietrich and Mohl at Cassel in Germany.

It is to be said, however, that experiments made in the laboratory of Lawes and Gilbert go to show that organic matters subjected to the action of ozone in certain stages of decay do not yield nitrates. In these trials it appeared, in harmony with what has been said already, that the best conditions for the formation of nitrates are found when the organic matters have been converted into the condition of old, slowly decaying humus.

Quantity of Nitrates in Soils.

One question of much interest is to determine how large an amount of nitrates is contained in ordinary soils, and in general the deportment of nitrates towards the soil. For the sake of the argument, it might be assumed that the nearer the farmer can bring the soil of his field to the condition of a saltpetre plantation, the more fertile will it be. But let him do his best, he can never accumulate a very large proportion of nitrates in his field, for the soil has little or no power permanently to retain these substances. Every rainfall dissolves the nitrates which have formed in the upper layers of the soil and carries them down into or towards the lower layers, and in case the rain should happen to be abundant and long-continued it may even wash the nitrates utterly out of the soil. The double

silicates which serve so well to arrest potash and ammonia have no power to stop the waste of nitric acid. One prime condition for the success of saltpetre making in the old plantations was the avoidance of the leaching action of rain. The heap of materials was either sheltered by means of a roof, or there were reservoirs below the heap in which to receive any liquid that might flow from it.

The following experiments of Boussingault forcibly illustrate the fact that nitrates are continually formed in cultivated soils during the summer months. Boussingault placed a couple of pounds of sifted earth upon a stone slab under a glass roof, and moistened the heap from time to time with pure water. The proportion of nitric acid in the soil was determined at the start, and afterwards at intervals during the course of the summer, with the following results.

1857.	Percent of Nitrate of Potash.	Pounds of Nitrate of Potash per Acre.
5th August	0.01	34
17th "	0.06	222
2d September	0.18	634
17th "	0.22	760
2d October	0.21	728

During the hot weather the formation of nitrates from the organic matter in the soil was rapid, but it appears to have received a check with the advent of cooler weather in the autumn. The soil experimented upon by Boussingault was from an old garden; it was porous and sandy, and had been heavily manured time out of mind. These experiments are in full accord with universal experience, that the formation of nitrates is most rapid in hot climates and in hot weather. They accord also with the observations of other experimenters, that a soil must not be dry, but somewhat moist, in order that nitrification shall occur. That is to say, the soil must be made a comfortable place of abode for the microdemes which cause nitrification.

Some old observations made by Touvenal, in France, may here be cited. In temperate climates, he says, the spontaneous nitrification of arable fields varies very much according to the kind of soil and the term of its exposure to the air. Generally speaking, however, from the point of view of a saltpetre boiler searching for nitrous earth, the amount of nitre formed in the fields is inconsiderable. Even at times when there has been no rain for a considerable interval, saltpetre can seldom be extracted anywhere in France from those cultivated soils that are either very sandy or very clayey.

Soils composed of mixtures of sandy, clayey, and calcareous loams, such as are common in France, rarely yield more than an ounce or an ounce and a half of saline matters to the quintal. Very chalky, fine, light soils, like those of Champagne, sometimes yield a little more, while the soils of kitchen gardens that are carefully tilled often yield considerably larger quantities. As much as four ounces of saline matters, consisting of a mixture of nitrates and chlorides, especially of lime and soda, have been extracted from each quintal of earth taken in spring, after two months of warm dry weather, from the garden of the Tuileries.

This amount was the largest obtained by Touvenal from the soils of gardens or fields where the earth was unsheltered and uncovered. But he remarks that such earth is as rich as perhaps half the nitrous earth that is taken from houses and cellars to be worked by the saltpetre boilers, or even as much of the earth which has been cultivated for nitre expressly in the artificial nitre beds.

The leaching action of rain is well shown by another experiment of Boussingault. He examined soil taken from a garden after a fortnight of hot, dry weather, and found in it as much nitric acid as would amount to rather more than 900 lb. of nitrate of potash to the acre, taking the soil as one foot deep. After three weeks of rainy weather, during which two inches and more of water fell, he again examined the soil, and found less than 40 lb. of nitrate of potash to the acre. During the month of September there were many rainy days, as much as four inches of rain having fallen in the course of the month. But on October 10th, after a fortnight of hot, windy weather, the garden had become so dry that it needed to be watered. On examination it was then found that the soil contained nearly 1,300 lb. of the nitrate to the acre. The soil of this garden was sandy and porous, and it had long been heavily manured. It is to be observed that, agriculturally speaking, some of the foregoing quantities of the nitrate are large. In field practice 200 lb. of nitrate of soda to the acre is esteemed to be a good dressing.

This rapid accumulation of nitrates in the upper layers of the soil after a few weeks of dry weather is a point to be specially insisted upon. Doubtless a very considerable part of these nitrates has been brought up from lower layers of the soil, and returned to the surface by means of the upward movements of the soil-water that are induced by the capillary action of the soil, the evaporation

of water at the surface of the soil, and the exhalation of water from the leaves of plants. Precisely the same phenomenon is witnessed in the saltpetre soils of the East Indies, where the surface of the earth becomes incrusted with nitrates during the dry season.

Nitrates are not leached from Soils rapidly.

The matter is instructive as illustrating the slowness with which nitrates must usually be washed out from the land during the summer months. Common observation and methodical experiments alike teach that the water of most summer rains does not soak into the earth to any great extent, and that its movements within the soil are slow. Most soils, moreover, have the power to absorb and hold larger quantities of water than a single moderate rain can bring to them, so that a large proportion of the nitrates which are carried into the soil by rain while crops are growing is still kept within reach of the crops by means of the upward capillary movement which sets in when the downward movement of the rain-water has ceased.

Practically speaking, it is probable for the great majority of cases that nitrate of soda applied to crops in the spring is not washed out of the land to any very serious extent before the autumnal rains; though farmers who use this fertilizer will do well to consider carefully the character of the soils to which they apply it, both as regards their situation and their capacity for holding water. It has been found that a much smaller amount of nitrates leaches out from the soil of fields that are covered with vegetation, than from land that is bare. On land constantly covered with a thick growth of grass, for example, the nitrates are so completely taken up by the plants that only a very small proportion of them goes off in the drain-water, while the drain-water that flows out from fallow fields is apt to contain nitrates in comparatively large quantities. In studying this matter, Lawes and Gilbert noticed that the power of plants to use up the nitrates in the soil is appreciably less whenever available inorganic food, especially potash and phosphoric acid, is lacking.

It is often well to keep Land covered with Vegetation.

The power of growing crops to use up nitrates which might otherwise go to waste, is one point to be counted in favor of a method of culture which has been commended by several American writers. The idea is to keep the ground covered with vegetation all the time, or as constantly covered as may be possible, in order to smother

weeds and to prevent the land from being baked by the sun or washed by rain. Thus, for example, if a crop of corn were upon the ground, rye might be sown among it in August, at the time when the corn is last cultivated. Since the surface soil is shielded by the crop and kept somewhat moist by dew and vapor that come from the corn leaves, the rye will germinate and grow slowly under the corn in spite of the shade until the corn is harvested, when, if the season is at all favorable, the rye will take a start and cover the ground before winter. The next spring the rye will begin to grow long before the weeds, and will soon cover the ground with a mat which will be more or less dense according to circumstances. Consequently, when the spring work of the farm begins, and the question arises what shall be done with the old corn-field, it is not a bare field that is to be dealt with, but a rye-field which has been established at the cost of scarcely any trouble, and which probably did very little injury to the corn crop.

Manifestly, the rye can either be left to grow, to be harvested as hay or as grain, in due season; or the young rye might be pastured in the spring and early summer, and the cropped sod be ploughed under for turnips or for Hungarian grass; or the growth of rye could be treated as green manure, pure and simple, and ploughed under for potatoes or for corn. The practice above described, though akin in one sense, is really different from some other instances of keeping land covered; as, for example, when rye is sown immediately after a grain crop, or on fields whence a crop of early potatoes or of sweet corn has been taken, and where, instead of leaving stubble, or a bare field, to itself, oats or barley are sown with the view of pasturing or mowing, and then ploughing under the green stubble late in the autumn. The peculiarity of the corn case is, that the interpolated crop uses the surface water, viz. that which dribbles as dew from the corn, or which is exhaled as vapor from it.

Summer Fallows may have Merit also.

In spite of the propriety of thus growing crops in autumn and spring to prevent loss of nitrates by leaching, it is none the less true, in view of what is now known of nitrification, that much more than has hitherto been customary may be urged in favor of summer fallows as a preparation for winter grain. As has been said already, Lawes and Gilbert found towards the end of summer from 34 to 55 lb. of nitrogen in the form of nitrates to the acre of fallow land; from which result they argue that the accumulation of nitrates

would probably enable the soil to produce twice as much wheat as it could have done without the fallow, provided the season has been fairly dry, and that the rains have not been heavy enough to wash away the nitrates before the autumn wheat plants could put them to profit. It would seem probable from this consideration, that a not too rainy climate is requisite in order that fallows shall have their best success.

Waste of Nitrates by Leaching.

Agriculturally speaking, all cultivated soils, with some rare exceptions, contain an appreciable quantity of nitrates. According to Knop, small quantities of nitric acid are even held in the insoluble condition in soils, in the form of highly basic nitrates of alumina and iron. These compounds alone among all the nitrates are insoluble in water. With this trifling exception, it is easy to wash every trace of nitrates out of a soil by means of water. In point of fact, enormous quantities of nitrates are incessantly being washed out of the soil and carried to sea. The water of field drains, brooks, rivers, lakes, and wells always contains more or less of the compounds of nitric acid, the proportion being largest, as a general rule, in populous and highly cultivated localities. The amount of nitric acid thus carried to sea is very large. It has been calculated that the River Rhine discharges daily 220 tons of saltpetre into the ocean, the little River Seine 270 tons, and the Nile 1,100 tons.

It is this inability of the soil to retain nitrates permanently, that has led many writers to recommend that nitrate of soda should be applied in successive portions, and there are published experiments that go to show the benefit of this course. For the same reason, nitrate of soda should be applied in the spring rather than in autumn. For the same reason, again, it may often be better policy to apply nitrate-forming manures rather than nitrates themselves.

Nitrates in City Wells.

The tendency of nitrates to flow out from the soil with the water, as well as the fact of the rapid formation of nitrates in the soil under favorable conditions, is capitally illustrated in the wells of crowded cities, as was just now said. As much as one part of saltpetre in five hundred parts of water has been detected in the wells of the older part of Paris, and it is easy to find well waters highly charged with nitrates in almost any city. Many years ago, I prepared a quantity of distilled water from the water of a well that had long been left unused in the cellar of University Hall in the College

yard at Cambridge. But the distillate was so highly charged with nitrous salts of ammonia that it was wholly useless for analytical purposes. There was at that time a large privy vault some forty or fifty feet from the well.

Nitrates in Air and Rain.

From what has been said already of the formation of nitrates by electric sparks and as an incident to combustion, and from the action of ozone on ammonium compounds, it follows that there must be more or less nitric acid in the air. It has in fact been proved to exist there by direct experiment. Not only can nitrates be detected in rain-water, in snow, hail, dew, and fogs, but by causing large quantities of air to bubble through alkaline solutions it is possible to collect enough of the atmospheric nitrate to prove its existence. Naturally enough, it is easier to detect nitric acid in rain-water, that is to say, in water that has fallen through air, than in the air itself, for the water in question collects nitrates from the enormous quantity of air through which it falls.

Detailed statements of the quantity of nitric acid brought down by rain may be found in the works of Knop and Boussingault, and in Professor Johnson's "How Crops Feed," p. 86.

It may be mentioned here, that Way found that the total amount of nitric acid (N_2O_5) brought down by rains, dews, etc., at Rothamsted, England, in 1855, amounted to 2.98 lb. per acre, and in 1856 to 2.80 lb. The quantity varied greatly in different months; in 1855 there was least in January and most in October (20 times as much as in January). In 1856 there was least in February and most in May (six times as much as in February). In Germany, Pincus found for the year ending March, 1865, that 7.23 lb. of nitric acid per English acre had fallen. Bretschneider found for the year ending April, 1866, 3.75 lb. nitric acid per acre. At Basel, in 1870–71, Goppelsroeder found that almost 14 lb. of nitric acid were brought down, per year and per acre, in the rain and snow.

With comparatively rare exceptions, there is more than enough ammonia in the air to neutralize the nitric acid. It is to be presumed, therefore, that the atmospheric nitric acid exists in the form of nitrate of ammonia. Goppelsroeder in his trials computed that 21¾ lb. of nitrate of ammonia were brought to the acre of land in a year by rain and snow. There are exceptions to the rule, however, for free nitric acid has occasionally been detected in the air

and particularly in hailstones. Indeed, one or two instances have been recorded where hailstones have actually tasted sour.

Since nitrate of ammonia is not appreciably volatile at ordinary temperatures, it is to be inferred that that which exists in the air is held there in mechanical suspension, just as the dust that is seen in the sunbeam is held suspended. There are many things thus perpetually floating in the air. It is a fact, for example, that there is so much salt dust in the air, brought inland by winds from the sea, that it may easily be detected at any time by testing the air for sodium with the spectroscope. On evaporating large quantities of rain-water to dryness, chemists have frequently found appreciable quantities of the nitrates of lime and soda in the residue left by the evaporation. Manifestly, the bases in question have been derived from dust in the air.

CHAPTER XII.

AMMONIUM COMPOUNDS.

LIKE the nitrates, ammonium salts, when applied to the soil, exert a marked influence upon the growth of plants.

Crops that are fed with ammonium salts soon acquire that deep green foliage which is so indicative of health and vigor. Both the absolute amount of the foliage and the proportion of nitrogen contained in it are distinctly increased by their use.

There can be no question as to the great value of ammonia and its compounds considered as fertilizing agents. This fact may readily be illustrated by watering almost any plant, standing in loam, with a highly dilute solution of an ammonium salt, and comparing the growth of this plant with that of another similarly situated, but watered only with water.

The widely extended use of Peruvian guano and of sulphate of ammonia, in Europe, shows the esteem in which ammonium compounds are there held by practical farmers. Indeed, until a comparatively recent period, many chemical writers were accustomed to regard ammonium compounds as the sole source from which plants could derive nitrogen. It was taught that not only the ossein of

bones, but even the nitrogenized constituents of barnyard manure, must change to ammonia in order to be assimilated by plants.

It is now known, much as still earlier writers supposed, that nitrates are on the whole better fitted than ammonium compounds for exciting vegetable growth; and it has been proved, as will be seen hereafter, that several other compounds of nitrogen, besides nitrates and ammonium salts, are directly assimilable by plants. But the fact that certain ammonium compounds are obtained cheaply and rather abundantly, as incidental products, which result from the manufacture of other and more valuable substances, puts it in the farmer's power to procure them if he so pleases.

Comparative Merit of Nitrates and Ammonia.

So far from ammonium salts being better than nitrates as plant-food, the tendency of modern investigation has been to show that the ammonium compounds are, generally speaking, inferior. The question was broached occasionally, not many years ago, whether quantities of ammonium compounds and of nitrates that are chemically equivalent have the same value for the plant, as sources of nitrogenous food. The significance of the inquiry will appear, in some part, on comparing the composition and the molecular weights of nitric acid and ammonia, as here set forth: —

Ammonia.		Ammonium.		Nitric Acid.			
				H	1		
N	14	N	14	N	14	N_2	28
H_3	3	H_4	4	O_3	48	O_5	80
NH_3	17	NH_4	18	HNO_3	63	N_2O_5	108 [$\div$ 2 = 54]

If it is the nitrogen alone of these substances which is of value as plant-food, and if one or the other of them is competent to give up its nitrogen to the plant with equal facility, then 17 lb. of ammonia (NH_3) would do as much good as 54 lb. of anhydrous nitric acid (N_2O_5), such as may be supposed to exist in the nitrates.

In favor of the view of the equivalency of the two substances, were the familiar facts that ammonium compounds and nitrates are rather easily transformed one into the other within the soil, and that ammoniacal manures, as well as those which contain nitrates, give excellent results in farm practice. It is true, moreover, that both ammonium compounds and nitrates occur habitually within the plant. Hosäus has shown that appreciable quantities both of ammonium compounds and of nitrates are contained in living plants, although the amounts of both these substances are subject

to wide variations, according to the stage of development of the plant. In grain plants he found that both ammonia and nitrates are most abundant in the spring, when vegetation begins, and that they are least abundant when the plants are in blossom. After the time of flowering, the amount of these constituents gradually increased again. Usually, there was more nitrogen in the form of ammonia in the plants than in the form of nitrates, though in half-ripe wheat he found nitrates to be more abundant than ammonium compounds.

Berthelot and André, on the other hand, who confined their attention to the nitrates, found that nitrate of potash became more and more abundant, in the plants they examined, from the moment when the seed germinated until just before the time of flowering. Subsequently, while flowers and fruit were being formed, the percentage proportion of the nitrate in the plants diminished; but it increased again when the process of fruition had wellnigh run its course, until the withering and death of the vegetable matter put a stop to the formation of nitrates by the plant cells.

This diminution of the nitrate during the period of reproduction is due to the using up of the nitrate nitrogen for the formation of amids and albuminoids that are needed for the making of flowers and fruit. There is no evidence, however, that nitrates are not really formed within the plant as freely at the time of fruition as before.

As has been stated in the previous chapter, nitrate of potash was found to be most abundant in the stems of plants, while the roots also contained considerable quantities of it. In other words, the nitrate was most abundant in those parts of the plant where most of it is formed. There was much less of it found in the rootlets and flowers, and especially in the leaves. Moreover, less of the nitrate was found in plants that were "forced" in such manner that they "ran to leaf," than in plants that developed normally; manifestly, because in leaves nitrates, as well as other things, suffer reduction.

The constant presence of ammonia in plants at all stages of their development, as observed by Hosäus, certainly seemed to be good evidence of the importance of ammonia nitrogen for vegetable growth. But, on the other hand, numerous experiments made in pots with artificial soils, and experiments made by way of water culture also, have, with some few exceptions, resulted decidedly in

favor of the nitrates, and adversely to the doctrine of equivalency. Speaking in general terms, it may be said that, while many experiments have shown clearly enough that nitrates are competent to supply many kinds of plants with all the nitrogen they need, it has been extremely difficult, if not impossible, to make some kinds of plants grow in solutions that were charged with ammonium salts instead of nitrates, as the source of nitrogen.

It was thought at one time that the chief trouble with the ammonium salts, in the water culture experiments, lay in their acids, which, as has already been stated, are apt to be set free when the ammonia of the salt is taken up by the plant. These acids would naturally corrode or poison the plant roots, in the absence of any soil to absorb and retain and neutralize them.

Some Kinds of Plants prefer Nitrates, others prefer Ammonia.

From a general review of all the experiments, it is hard to escape the conviction that some kinds of plants may need or prefer ammonia at one stage of their growth, and nitrates at another stage. It is not at all unlikely, indeed, that at still other stages of growth plants may prefer still another form of nitrogenous food, different from either the nitrates or the ammonium salts.

There is a wide field for investigation in this regard, for comparatively few experiments have been made thus far for the express purpose of elucidating the problem. Among the most important experiments which have been made in this sense are those of Julius Lehmann, who proposed to himself squarely the question whether ammonium salts or nitrates are best suited to supply plants with nitrogen. He offers the results which follow, as one small contribution to the solution of this question.

In the first place, he grew a number of buckwheat and of maize plants, by way of water culture, in solutions which were all of one and the same composition in respect to their inorganic constituents, but which differed from one another in that some of the solutions contained nitrate of lime while others contained sulphate of ammonia. There were two rows of jars, each row containing eight jars, and to one row nitrate of lime was given while the other row got sulphate of ammonia.

The buckwheat plants grew very well in the solutions that contained the nitrate, — as well indeed as they would have grown in a garden, — but they grew very badly in the solutions that contained the ammonia salt. The two best buckwheat plants grown in the

nitrate jars were 130 and 140 cm. high (i. e. 50 and more inches); they bore 238 and 174 seeds, and weighed (air-dried) 29 and 27 grams.

Many investigators have grown luxuriant buckwheat plants in solutions, and in sand, that contained nitrates as the only nitrogenous food; and experiments made by S. W. Johnson, as long ago as 1861, ("How Crops Feed," p. 302,) plainly indicated the inferiority of ammonium compounds as compared with nitrates, for this particular crop.

Lehmann's maize plants were placed in the jars on the 19th of June, after they had germinated. After the lapse of eight days the plants in the nitrate jars exhibited all the signs of starvation. But the plants that had been placed in the ammonia jars behaved in a totally different way. They immediately began to grow most luxuriantly, and exhibited convincing evidence that they were abundantly fed with the right kind of food.

After the experiment had lasted six weeks, the appearance of all the plants, both those in the nitrate jars and those that were fed with ammonia, suddenly changed. The nitrate plants became green all at once, although no change had occurred in respect to the outward conditions under which they were growing; and from this time forth the nitrate plants grew rapidly and well.

But with the ammonia plants precisely the reverse of all this occurred at the very same time. The leaves of the ammonia plants lost their healthy color, and the plants themselves presented an unhealthy appearance. While the nitrate plants grew continually and developed normally until the 15th of September, the ammonia plants did not increase, but remained standing in a most miserable condition. Moreover, the weight of the nitrate plants when harvested attested their normal development.

On changing some of the sickly nitrate plants, during the first period, into jars that contained the ammoniacal food, they revived immediately and took on a lively green color in two days' time; and so, conversely, on putting some of the healthy ammonia plants into a solution that contained nitrate of soda, they became at once pale and sickly.

So too, during the second period, when it appeared that the maize plants had need of nitrogen in the form of a nitrate, such shifting of the plants from one kind of jar to another immediately exhibited the advantage of this kind of food. Lehmann tried this

changing of some of his plants repeatedly, and found that he had it completely in his power to make the plants pale and sickly, or green and healthy, as he might will.

From these experiments with maize, it would appear that this plant has need of ammonia when young, and of nitrates when more mature. But manifestly, if this apparent fact be really true, the whole theory and practice of manuring Indian corn will need to be revised.

It should here be said that earlier experiments upon maize, as cited in "How Crops Feed," pp. 303, 304, though seemingly somewhat conflicting, do none the less point to the conclusion that this plant can be supported by ammonia during certain stages of its growth. One experimenter found, for example, that maize could be grown with ammonia, while oats invariably failed.

Lehmann next proceeded to experiment with tobacco. But in this case he grew the plants in quartz sand instead of by way of water culture. He supplied the plants, as before, with all the mineral matters they needed, and to some of the plants he gave, in addition, nitrate of soda, while to others he gave sulphate of ammonia.

Here, with the tobacco, the plants that were fed with ammonia were healthy and sound from first to last; the stalks and leaves were always succulent and green, and the plants grew normally all the while. The nitrate plants, on the contrary, remained far behind the ammonia plants during the first half of the experiment, and, being of pale color, had a sickly appearance. But during the last half of the experiment the nitrate plants exhibited a strong tendency to improve. They became green, and their growth was evidently stronger than before. In spite of this improvement, the final weight of the nitrate plants was comparatively small. It turned out that the crop of ammonia plants was six times, and the crop of nitrate plants three times, as heavy as a crop grown in sand without any addition of nitrogen.

Here it would seem as if ammoniacal manures, rather than the nitrates, were "indicated" for the tobacco plant. With buckwheat, it will be remembered, the fact was just the other way. The buckwheat plants prospered with nitrates from first to last, just as Boussingault's small sunflower prospered.

The fact that the tobacco plants got some good from the nitrate during the second stage of their growth supports in some sort the

results that were obtained with the maize, for the maize plants when mature put the nitrate to good use. As Lehmann suggests, it may be that all his tobacco plants really fed upon nitrates during the last half of their life; for it might easily have happened that the ammonia salt was changed to a nitrate, and this oxidation would be more likely to have occurred in the sand jars than in those used for water culture, since in the latter the solutions were frequently changed.

The readiness with which ammonium compounds change to nitrates in such experiments has often been remarked upon, both in respect to sand culture and water culture. Indeed, this liability to change constitutes one of the many difficulties which make the question of the comparative merits of ammonia and nitrates so hard to solve. In field experiments, for example, with ammonium salts it might always be argued that, since ammonia changes readily to nitrates in porous soils during the growing season in presence of the nitric ferment, it may after all be nitrates, and not ammonia, that feed the crops.

Curiously enough, it has been noticed in some experiments in water culture with ammonium salts, that, after long-continued sickly growth, the plants have suddenly thrown out new shoots, and have begun to grow vigorously. Examination of the solutions has then shown that a large part of the ammonia had really been changed to nitrates, and the inference was plain that the new growth must have been due to the formation of the nitrates.

Lehmann next experimented with the yellow lupine, which is a plant that contains a great deal of nitrogen, but which nevertheless grows upon extremely sterile land. The lupine has been found to succeed perfectly upon the sandy heaths of Germany where hardly anything else will grow, and it has always been rather mysterious as to how and where it gets its nitrogen.

Lehmann grew his lupine plants in quartz sand; he fed them all with the necessary ash ingredients, and to some he gave no nitrogenous food, to others he gave nitrate of soda, and to others sulphate of ammonia. To all outward appearance the lupines that got nitrate of soda grew best of all. Compared with the other plants, they were stronger, and they were developed more symmetrically. But at the time of harvest it appeared that the seeds of the nitrate plants weighed less than those from the ammonia jars. In a word, the nitrate of soda produced a good deal of leaf, but comparatively

little seed, — a result which goes to show that these plants got too much nitrogen.

The lupines fed with sulphate of ammonia began to look miserably as soon as they had developed three or four leaves. The leaves were crumpled and yellow; several of the plants died after a short time, and the remainder were crippled and feeble, until in July a change came over them. They began to grow vigorously, and developed many flowers, from which seeds ripened in due course, in a perfectly normal way.

As for the lupine plants that got no nitrogenous food, they held way, during the first week or two, with the nitrate plants; during the next ten weeks, they fell behind somewhat, but caught up again afterwards to such an extent that only a slight difference could be detected on comparing the best plants of the two lots, although there were many more good plants to be found among the nitrate jars than in the no-nitrogen jars. Still, at the time of harvest, the no-nitrogen crop gave a larger yield of seeds than the nitrate crop or the ammonia crop. The weights of the seeds were, with

No Nitrogen.	Ammonium Sulphate.	Sodium Nitrate.
143 grams.	133 grams.	128 grams.

It would appear, then, in this case, that the nitrogen originally contained in the lupine seeds that were sown, aided perhaps by some nitrogen in the sand, and that of insects caught by the plant from the air, was sufficient for the growth of the plants. More than this, the chemicals may have distressed the plants to which they were applied. The inference is that lupines need but little nitrogen during a part of their life, or rather that they can continue to live when they have access to but little nitrogen.

Another point to be mentioned is the very great influence that temperature exerts upon the growth of the lupine. It is a plant that loves warmth, and it is not unlikely that the sudden improvement in the growth of the ammonia plants in July may have been caused by a change of temperature, though it may be true that the formation of nitrates from the ammonia was the real cause of the improvement. The lupine needs to be studied much more carefully than has ever been done hitherto, and that too by chemists familiar with horticultural practice and with the habits and requirements of this particular plant; but in so far as Lehmann's experiments go, it seems evident that nitrates were better able to feed it than the ammonium salt.

Weiske has recently grown tolerable lupine plants by way of water culture, using nitrate of lime as the source of nitrogen. The nitrate plants were decidedly better than those fed with nothing but ash ingredients, and they contained ten times as much nitrogenous matter.

Eckenbrecher also found that lupines are better able than peas to feed upon nitrates. In his experiments the lupines put nitrate of soda to good use, while peas used but little of it, and could not bear the presence of an excess of it in the soil. Boxes 1½ feet deep and ¾ of a yard in area were filled with sterile sand which was admixed with the necessary ash ingredients and with quantities of nitrate of soda ranging from 1 to 10 grams. The quantities of air-dried plants harvested are given in the following table.

Grams of Nitrate of Soda used.	Peas. Seeds, Grams.	Peas. Total Crop.	Yellow Lupines. Seeds.	Yellow Lupines. Total Crop.
0	60	140	6	36
1	85	194	14	77
2	75	161	28.5	110
5	61	145	39.5	153.5
10	65	143	44	144

Hosäus grew peas in pots of peat charged, in addition to ferric phosphate, in one instance with sulphate of potash, sulphate of magnesia, and chloride of ammonium; in another, with the nitrates of lime and of potash, and sulphate of magnesia; and in a third, with a mixture of all these salts. None of the plants were vigorous, though those which had access to the nitrates were better than those fed with the ammonium salt. On analyzing the plants at the end of one and of two months, nitrates were found in all of them, and there was as much or more in those fed with the ammonium salt as in those fed directly with nitrates.

Heiden has found that neither lupines nor rye can make use of ammonia salts in the earlier stages of their growth. In field experiments with oats, also, he found that nitrate of soda applied as a top-dressing to the young plants gave rather better results than sulphate of ammonia that had been worked into the soil a short time before sowing the seed. On a soil that had been formed from the disintegration of granite, he found that a dressing of 30 or 40 lb. of soluble phosphoric acid, and from 7 to 14 lb. of nitrogen (i. e. 53 to 100 lb. of nitrate of soda) to the acre, gave profitable returns with oats.

Wein grew oats, peas, horse-beans, and soy-beans in mixtures of pure humus (prepared by acting upon sugar with chlorhydric acid)

and ash ingredients, with additions of one or another form of nitrogen. All the plants grew well with nitrate of soda; but sulphate of ammonia hindered their early development, and many of the plants were killed by it.

After a time, however, those plants which still remained alive were able to put the ammonium salt to use; perhaps when some of it had changed to a nitrate? Similar results were obtained by Wein with soy-beans grown in a calcareous sandy soil rich in humus. Plots between 3 and 4 square metres in area were dressed with 120 grams of a plain superphosphate of 27%. To plot No. I. no nitrogenous fertilizer was added, while No. II. got 20 grams of nitrogen in the form of nitrate of soda (121½ grams), and No. III. got 20 grams of nitrogen in the form of sulphate of ammonia (94.3 grams). The weights of the crops harvested were as follows:—

Plot.	Fertilizer.	Weight in Grams of Grain.	Shells.	Straw.	Total Dry Crop.	Total Albuminoid Matters.
I.	No nitrogen . . .	381.3	233.0	806.5	1,242.8	202
II.	Nitrate of soda . .	1,185.2	478.1	2,102.0	3,332.4	670
III.	Sulphate of ammonia	944.6	382.0	1,621.0	2,603.3	574

In this case both of the nitrogenous fertilizers did good work, but especially the nitrate of soda. The plants that received the sulphate of ammonia were backward during the earlier period of their development, but they recovered themselves afterward.

Baeyer had previously failed repeatedly in persistent efforts to grow oats with ammonium salts by way of water culture. The ammonium compounds distressed the young plants, and it was proved in these trials that it was only after some of the ammonia had changed to a nitrate that the oats prospered.

Hässelbarth grew barley in pots of sand admixed with needful amounts of ash ingredients, which were supplemented in some cases with nitrates, and in others with ammonium salts. The results of all his trials went to show that, while the nitrates were proper food for this crop, the barley plant could not supply itself with nitrogen directly from the ammonium salt. When the conditions were favorable for the nitrification of the ammonium compounds, the barley grew with more or less luxuriance, according as the nitrification was more or less rapid.

Kellner grew rice by way of water culture in solutions that were alike as to ash ingredients, but different in that some jars got nitrate of potash, others a mixture of nitrate of potash and nitrate of lime, others phosphate of ammonia, and others mixtures of nitrates and

the ammonium salt. At first the ammonia plants were superior to those fed with nitrates; they were higher, and seemed to be healthier. But later the nitrate plants recovered their vigor, while the ammonia plants suddenly came to a standstill. As the condition of the ammonia plants failed to improve, nitrate of potash was given to a number of them, after some time, with the result that they began to grow again, although those which had no other source of nitrogen than ammonia remained crippled to the end of their lives. The plants which were fed from the first either with nitrates, or with a mixture of nitrates and the ammonium salt, did well.

Farm experiments made in Germany, at Maercker's suggestion, on sugar beets, showed that while 1 cwt. of nitrate of soda gave an average increase of from 25 to 30 cwt. of beet roots, the same amount of nitrogen applied in the spring in the form of sulphate of ammonia ($\frac{3}{4}$ cwt.) gave an increase of crop amounting only to 15 or 20 cwt. When the ammonium salt was applied in autumn, however, almost as good crops were obtained as those got from nitrate of soda.

A very striking experiment has been made by Dietrich to test the comparative efficacy of ammonium salts and nitrates in producing morphine in poppy plants. The plants were grown on a sandy soil that contained very little nitrogen. When no manure was used, the opium produced contained no more than $\frac{1}{2}\%$ of morphine. But there were 3 or 4 times as much morphine in the opium from plants fertilized with nitrate of soda, and 13 times as much in that from plants fertilized with sulphate of ammonia. Analogous experiments by Broughton on cinchona plants manured with sulphate of ammonia, guano, and farmyard manure, go to show that, at different stages of growth, one or another kind of nitrogen may be best fitted to promote the formation of alkaloids.

Hosäus grew onions by way of water culture in solutions that contained, beside ferric phosphate, No. I. sulphate of potash, sulphate of magnesia, and chloride of ammonium; No. II. the nitrates of lime and of potash, and sulphate of magnesia; and No. III. a mixture of equal parts of Nos. I. and II. At first the plants grew equally well in all the jars, but subsequently those in the ammonia jars fell behind, and several of them died, though no difference was noticed between the plants in the other two jars. At the end of six weeks, analysis showed the presence of nitrates in the roots and bulbs of all the plants, but not in the leaves. In the plants that had been

fed with nitrates alone, it was only in the roots that any great amount of nitrates was discovered. Ammonia, on the contrary, was contained in all parts of those plants which had been fed with the ammonium salt, though it was as good as absent from the plants which were fed with nitrates alone. Hence the inference that living plants have power to convert ammonium compounds into nitrates; while, as regards the case now in question, there was no evidence of any power in the plant to change nitrates to ammonia.

It was noticed by Hosäus moreover, in other experiments, that the bulbs of onions, as well as those of leeks and the sword-lily, contained no nitrates in October, although they contained no inconsiderable quantity of nitrates in June.

As regards potatoes, Wagner concluded from field experiments that ammonium salts do harm rather than good. He found that ammonia hindered the vegetation of the crop, and made the plants sickly and of a yellowish color. In a case where the conditions as to soil and temperature were such that the ammonia could not readily change to a nitrate, dressings of 40 kilos of nitrogen to the hectare, applied in the form of sulphate of ammonia, gave no increase of the potato crop; while, under similar conditions, dressings of 40 kilos of nitrogen in the form of nitrate of soda gave an increase of crop amounting to 28%.

Maercker in his field experiments with potatoes found no great difference between nitrate of soda, sulphate of ammonia, and Peruvian guano, when used by themselves or in conjunction with plain superphosphate. A notable increase in the yield of potatoes was obtained by the use of either of these nitrogenous fertilizers, almost always, even when they were applied by themselves, but light dressings of the nitrate gave comparatively larger yields than heavy dressings. No useful effects were derived from nitrogenous fertilizers of organic origin applied to potatoes in the spring, either by themselves or with superphosphate; and no appreciable increase of crop was obtained when superphosphate was used by itself. But when the superphosphate was applied in conjunction with an active nitrogenous fertilizer, much better results were obtained than could be got by the nitrogen compounds alone, provided the superphosphate was used in large quantity.

When no dung was used, the best results were got from mixtures of nitrate of soda and a large quantity of superphosphate, i. e. 350 lb. to the acre of Baker Island superphosphate, such as contains 18

or 20% of soluble phosphoric acid. Where no farmyard manure is to be used, Maercker suggests as a normal dressing for potatoes 350 lb. to the acre of Baker Island superphosphate and 175 lb. of nitrate of soda.

In another set of experiments, Maercker found that nitrate of soda was a useful addition to farmyard manure, and for this purpose it proved to be superior to sulphate of ammonia, though, unless the nitrate was applied at or shortly after the time of planting, it did harm and diminished the crop of potatoes both as to quantity and quality. Here again nitrogenous fertilizers of organic origin, though used in conjunction with farmyard manure, did no good.

Plain superphosphate used as an addition to farmyard manure gave a very considerable increase in the yield of potatoes, and such addition was found to be highly satisfactory in many instances. But the largest crops of all were obtained by using stable manure, superphosphate, and nitrate of soda together. In this case much smaller quantities of superphosphate were sufficient than when it was used without the dung. 175 lb. of Baker Island superphosphate, and from 80 to 125 lb. of the nitrate, are deemed to be fit additions to a dressing of fresh farmyard manure.

Dreschler also, in very elaborate farm experiments on potatoes in Germany, found that nitrate of soda used with superphosphate almost invariably gave good results, and that, with few exceptions, the advantage was in getting increased yields of large tubers.

In respect to sugar-beets, it appears that extremely large dressings of sulphate of ammonia are not only inferior to nitrate of soda, but that they may even do positive harm to the land. On a somewhat calcareous soil at Grignon, in France, Dehérain obtained the results set down in the table:—

	Kilos of Beets from the Hectare. 1876.	1877.	1877.[1]
No manure	17,400	30,600	46,600
400 kilos nitrate soda to the hectare	19,000	36,900	56,700
400 " ditto and 400 superphosphate	21,400	....	....
1200 " nitrate soda	21,400	29,800	57,400
400 " sulphate of ammonia	16,400	29,950	41,600
400 " ditto and 400 superphosphate	16,400	....	....
1200 " sulphate of ammonia	14,600	20,000	37,200

The harm done by the ammonium salt was even felt in subsequent years. During 1879–80 esparcet followed the beets and gave the following amounts of hay. In 1880–82 grain was grown on

[1] Another variety of beet.

the same fields without any additional manure. The means of the three grain crops are given at the right hand of the table.

	Kilos of Clover Hay.	Kilos of Grain.	Kilos of Straw.
No manure	5,863	2,110	3,258
400 kilos nitrate soda	6,249	2,400	4,000
1,200 " " "	6,815		
400 " sulphate of ammonia	5,812	2,170	3,500
1,200 " " "	4,261	2,000	2,780

Stoeckhardt, on comparing the results of all the field experiments upon sugar beets that had been published in the course of several years preceding 1862 found that nitrate of soda gave better crops than ammonium salts in 7 experiments out of 11; than bone-meal, in 14 out of 22; than superphosphate, in 20 out of 29; than rape-cake, in 15 out of 20; but that Peruvian guano did better than nitrate of soda in 11 experiments out of 22; and better than ammonium salts, in 9 out of 10.

In general, it appeared from the experiments of seven years, made in 23 different localities, that of the 100 largest crops 96 were obtained by the use of easily soluble nitrogen compounds, and only 4 when these fertilizers were absent. 77 of the largest crops had received phosphates (usually superphosphate) and 23 of them had not.

One fact to be remembered is, that nitrates, at least in warm and temperate climates, appear to be naturally supplied to plants much more freely than compounds of ammonia are. Most soils contain appreciable quantities of nitrates, and many soils contain them in very considerable quantities. But very few soils contain at any one time more than faint traces of ammonium compounds, as will be explained directly, though it may still be true that small quantities of ammonia are continually formed in the soil.

Desmarest has noticed that several plants apt to accumulate nitrates, such, for example, as borage, sunflower, and pellitory, remain dwarfed and stunted unless nitrates are added to the soil in which they are standing or unless the conditions are favorable for nitrification there.

The upshot of all these experiments is, that, while there are some plants that feed upon nitrates during their entire life, there are other plants that can feed upon nitrates only when they are mature; and that, while there are some plants that are benefited exceedingly by ammonia when young, there are others which get no good from it in the earlier stages of their development.

As Lehmann remarks, these facts have evidently some connection with another set of facts, observed by practical men; viz. that some crops can grow luxuriantly on land that has just been dressed with fresh dung, while other crops need to be fed with well-rotted manure. As bearing upon this matter a remark of Dr. Gilbert may be cited, viz. that nitrate of soda has been found in the field experiments of Mr. Lawes and himself to act much more favorably, as a manure, upon the growth of highly nitrogenous leguminous crops, such as peas, beans, and clover, than sulphate of ammonia. On the other hand, long experience in farming practice has shown that the ammonium salts are extremely well fitted for manuring wheat and barley; and Lawes and Gilbert have found that, when spread upon a lawn, they encourage the growth of the true grasses, as distinguished from clover and weeds.

Ammonium Salts change readily to Nitrates in the Soil.

Although, as has been said, the study of the question is complicated not a little by the easy conversion of ammonium salts to nitrates in the soil, the very fact of such conversion makes the question one of less practical importance than might at first be supposed; for in most cases where ammonium salts are employed as fertilizers, some part of them is soon changed to nitrates in the soil. And the nitrates are known to be useful in most cases, and to mature plants. It is the cases in which ammonium compounds particularly favor the growth of young plants that need to be specially studied, and allowed for in field practice.

The change of ammonium compounds to nitrates in the soil is usually so nearly complete in temperate climates, that it is hard to find more than a mere trace of ammonia in the earth at a depth of six feet, and there is small reason to doubt that, when a field is manured with ammonium salts in warm climates, a very large proportion of the nitrogen taken by plants from that field will be taken in the form of nitrates.

Thus, in the following experiments of Heiden, made at an earlier period than those just now cited, where sulphate of ammonia was found to be a profitable manure for grain though not for leguminous plants, there is good reason to believe that much of the ammonium salt was changed to a nitrate before it was used by the crops. In the case of the oats grown in 1869, for example, on land that had received the ammonium salt in 1868, there must have been ample time for the formation of much nitrate, and the fact that in 1870

the plot that had been fertilized in 1868 gave no better crop than the unmanured land goes to show, not only that nitrate had been formed, but that it had been all washed out of the soil in the course of the two years. So it was with the rye of 1875 also.

The results given in the table refer to plots of land of 18.44 square metres, which received respectively either one kilogram of sulphate of ammonia at the stated dates, or nothing at all.

Year of Growth.	Kind of Crop.	Sulphate of Ammonia applied in	Crop from the Fertilized Plots.		Crop from the Unmanured Plots.	
			Grain, Grams.	Straw and Chaff.	Grain, Grams.	Straw and Chaff.
1869	Oats	1868	3,090	5,885	820	2,090
1870	Oats	1868	89	322	89	320
1871	Oats	1871	5,267	9,185	167	523
1872	Vetches	1872	2,233	7,214	1,666	6,399
1873	Rye	1873	4,298	13,523	825	2,525
1874	Clover	1873	....	3,942	....	12,472
1875	Rye	1873	1,190	2,642	1,595	3,730
1876	Peas	1873	2,035	6,700	4,220	7,030
1877	Rye	1877	8,380	10,568	970	1,902

It cannot be said, however, that ammonia is never taken in as such by plants, for Hosäus has found an abundance of ammonia, as well as of nitrates, in a great variety of plants, in all parts of the plants and at all stages of development. Indeed, it would appear from his researches that ammonium compounds are more universally present than nitrates in the juices of plants; for in some plants, at certain seasons, he was not able to detect nitrates, though ammonia was exhibited in abundance. It seems probable withal, that in cold Northern countries nitrates from the soil must naturally play a very subordinate part in the nourishment of plants.

Nitrates often accumulate in Plants.

It has long been known that, under some conditions, very considerable quantities of nitrates not infrequently collect in various kinds of plants that have grown on rich soils. Lorgna, for example, found "a prodigious quantity of nitre" in sunflower plants that had grown on compost heaps, and none, or next to none, in those that had grown in the open fields. I have myself seen purslane, taken from a garden border, so full of nitrates that, when dried, the plant burned like touch-paper. Several of the earlier chemists, notably Lemery, John, and Baumé, and likewise Vannes and Granit, insisted strongly upon this point; and long lists of plants have been made out from which considerable quantities of nitrates may not infrequently be extracted. Succulent, rank-

growing plants are thought to be specially liable to contain nitrates, and those that grow about walls and refuse heaps. The sunflower, borage, fumitory, pepper-grass, henbane, thorn-apple, tobacco, beets, and many other plants, have been mentioned as rich in saltpetre.

The fact that large quantities of nitrates can be stored in plants in this way, accidentally as it were, is a very curious one, for it would seem at first sight as if the plants would, if they could, make immediate use of this form of nitrogen, and build up by means of it the various albuminoid constituents which are so essential for the life and growth of all kinds of plants.

Indeed, the experiments of Emmerling on bean plants go to show that nitrates taken up through the roots from the soil are changed to organic nitrogen compounds (amids) in the green parts of plants, especially in the leaves, and that these amids subsequently change to albuminoids. It was found, at all events, that while the roots and stems of the bean plants contained appreciable quantities of nitrates, no more than minute traces of nitrates could be detected in the leaves and buds, or in the flowers or fruit. Conversely, the proportion of amids was largest in the fresh new parts of the plants, where life was most vigorous and the formation of new matter most abundant, as other investigators had previously noticed, and as Berthelot has insisted since then. Emmerling argues that ammonia, as compared with nitrates, must play a very subordinate part in forming amids in the (bean) plant, since he found more ammonia in the leaves than in the stems, whereas, if ammonia were really used up in the leaves with any rapidity, it would be difficult to detect any of it there.

It has not yet been determined what connection, if any, exists between the storage of nitrates by various plants, as above described, and the preferences of plants for nitrates rather than for ammonium salts.

The Use of Nitrate of Soda in Agriculture continually increases.

Of late years nitrate of soda seems to be used in farm practice more freely than sulphate of ammonia, simply because the nitrogen in it can be bought for less money nowadays than that in sulphate of ammonia, as will be explained directly. A great deal of sulphate of ammonia appears still to be used in England, however, and it has been taught there that, while nitrate of soda does best in a dry season, sulphate of ammonia is to be preferred in a wet one.

It may be a merit of sulphate of ammonia, in some cases, that it acts more slowly than nitrate of soda. But either of these fertilizers would naturally produce its chief effect upon the one crop to which it has been applied. No gain can be expected from either of them in the second year even. They have no "endurance," such as is almost always counted upon when farmyard manure is used.

Leaves can absorb Ammonia and Carbonate of Ammonia.

It is a very interesting fact, that ammonia gas and the vapor of carbonate of ammonia can be absorbed by the leaves of plants. As has been stated already, it was observed some years since that the growth of plants in conservatories is greatly promoted by placing lumps of carbonate of ammonia upon the steam-pipes, so that the air with which the plants are bathed may be slightly charged with the vapor of the salt. Or, instead of the carbonate, a mixture of sal-ammoniac and slaked lime might be used. It is only necessary to keep the proportion of ammonia in the air so low that no more than four ten-thousandths of the salt be present in the air at any one time. Otherwise, some of the more tender plants might be injured. It does not appear that sunlight has any influence upon this absorption of ammonia through the leaves. It is not improbable, on the contrary, that the ammoniacal vapors may be seized and held by the acid juices of the plant.

The tendency of nitrogenized manures to increase the growth of foliage, rather than of seeds or fruit, may be remarkably illustrated by exposing a plant to the vapor of carbonate of ammonia at that moment of its development when the growth of leaves and branches ceases and that of the flowers begins. The development of the flowers will usually be checked at once, — or, even in case the flower is formed, it will be sterile and will yield no seed, — while the stem and the leaves take a new lease of life and proceed to grow vigorously.

Ammonia of the Air.

In spite of all that has just been said, the power of plants to absorb ammonia from the air is practically less important than might at first be supposed. The proportion of ammonia naturally present in the air is so insignificant that it cannot be supposed to have much direct influence upon the growth of vegetation, and in point of fact it does not. It is only when the atmospheric ammonia has been accumulated and brought down to the earth by rain

or dew, and has soaked into or been fixed in the soil, that it acquires any real significance. But it is then the roots of the plants, and not the leaves, that have to do with the ammonia: it has been transferred from the air to the soil-water. In any event, however, the proportion of ammonia naturally present in the air and in soils is so small that it must be of quite secondary importance for the support of plants as compared with the nitrates naturally found in the soil.

Sulphate of Ammonia.

Of the various salts of ammonia, the sulphate specially interests the agricultural student. It is particularly important, since, with the exception of Peruvian guano, it is the only commercial source of ammonia within the farmer's reach. True guano, such as comes to us from Peru, contains much ammonia combined with uric, oxalic, and phosphoric acids, as will be explained in due course.

Sulphate of ammonia is prepared in very large quantities from the ammoniacal water which is obtained incidentally in the manufacture of illuminating gas from coal.

Bituminous coal contains a certain small proportion of nitrogen, just as do humus and peat; and when either of these substances is subjected to destructive distillation, ammonia is given off from it, together with aqueous vapor, illuminating and other gases, and a variety of tarry and oily products. On cooling these products of distillation, the water and the ammonia condense together to form the so-called ammoniacal liquor.

This gas liquor varies widely as to the proportion of ammonia contained in it, both according to the kinds of coal used at the works, and to the methods employed for purifying the gas. Speaking in very general terms, it may be said to contain on the average about 1% of real ammonia (NH_3). The ammoniacal liquor cannot well be used by itself as a manure, because it is so bulky that the small amount of ammonia in it cannot be cheaply transported, and because it is contaminated with several substances that are poisonous to plants. Even the carbonate of ammonia in it might kill plants unless the liquor were mixed with some 10 or 12 times its bulk of water before applying it. Cases are on record where a mixture of one part of the ammoniacal liquor with no more than three parts of brook water was found to be injurious to a variety of crops.

Sulphate of ammonia is prepared by driving out the volatile ammonium compounds (carbonate, sulphide, and sulphocyanide) from

the gas liquor by means of heat, and collecting them in sulphuric acid, where the sulphate is deposited in the form of small, gray, sand-like crystals. As thus obtained, sulphate of ammonia has been used by thousands of tons in European agriculture, and it was formerly sometimes used in this country also for reinforcing a few of the better kinds of ammoniated superphosphates. It appears to be used in this way to-day as an addition to inferior cargoes of guano.

So far as the results of field practice are concerned, it was a not unnatural inference that sulphate of ammonia commonly acts directly as plant food. It increases the vigor of the plants, and enables them to take up more of other kinds of food in a given time than they could take up if they were not thus excited. Of course, the sulphate, applied alone, is far enough from being a complete manure. But it is none the less useful as an adjunct to slow-acting manures, or as one term among the manures in a judicious course of rotation. It has been found, moreover, to answer an excellent purpose upon many European soils, in which, through long-continued, injudicious, ignorant, rule-of-thumb cultivation, some kinds of plant-food have accumulated to an unnecessary extent.

The Field Experiments of Lawes and Gilbert.

In illustration of this point, some of the famous field experiments of Lawes and Gilbert may here be cited. These experimenters manured a large plot of land during many consecutive years with nothing but ammonium salts, and they found that the crop of wheat taken from the plot thus manured was every year considerably larger than that taken from a similar and adjacent plot which received no manure; though, naturally enough, the yearly increase of crop diminished as time went on. During the first 9 years the increase due to the ammonium salt was rather more than 9 bushels to the acre, while during the next 10 years the increase averaged only 7¼ bushels.

By the same set of experiments it was found that the application of soluble mineral manures alone to wheat upon that land produced little or no useful effect, unless an ammonium salt or some other source of active nitrogen was used in conjunction with the minerals. Upon the land in question a complex mineral manure, which supplied annually more of potash, magnesia, lime, phosphoric acid, and sulphuric acid than were taken off in the crops, gave a yearly increase of only about 3 bushels over the land that received no manure

whatsoever, and nearly 17 bushels less than was obtained by means of farmyard manure. This last result is the more noteworthy, in view of the fact that the manure was applied to land which had been previously enriched during several years by the accumulation of unexhausted residues from ammoniacal and mineral manurings.

The largest crops were obtained when mineral manures and nitrogenized manures were employed together; the yield being then in some instances far greater than that obtained by the use of farmyard manure. But the point to be specially insisted upon now is, that, since the ammonium salts alone increased the produce of the field very much more than the mineral manures alone, and continued to do so for a long series of years, it is obvious that that soil contained a considerable excess of available mineral matters over and above its available supply of nitrogen.

In many parts of Europe the soil, through long-continued cultivation and the abundant application of dung and straw, is apt to become charged with an excess of the ash ingredients of plants, — just as was the case with the experimental plots of Lawes and Gilbert. Hence the advantage of applying a certain proportion of easily assimilable nitrogenized manure to the land, in order that the plants may be incited to feed close, as it were, and utilize fully the manure which is within their reach.

Manner of using Sulphate of Ammonia.

The usual method of applying sulphate of ammonia is at the rate of 100 or 125 lb. to the acre on land which has previously been richly dressed with farmyard manure. It may either be used for top-dressing, or be worked in lightly just before seeding. In order to secure the even distribution of the small quantities usually employed, it is said to be well to mix the salt with 3 or 4 times as much loam. It is applied to grain crops in particular, and almost always, as one may say, as an addition to other manures. Practically, it is seldom or never used alone, not even when in a course of rotation it follows a phosphatic manure.

The best use of it seems to be upon grain crops when they are well above ground in the spring, and on mangolds or the like after they have been weeded. Light dressings of it might be used also on the very best mowing-fields after growth is well started in early spring, and again, perhaps, after mowing, in order to keep down weeds and inferior plants by insuring a vigorous and enduring growth of the true grasses.

Lawes and Gilbert's Experiments.

The increase of produce obtained in the experiments of Lawes and Gilbert by combining the mineral and the ammoniacal manure was remarkable.

The same amount of mineral manure which by itself gave scarcely any increase, and the same amount of ammonium salts (400 lb. to the acre) which when taken alone was less efficient than farmyard manure, and which diminished in efficiency from year to year, gave when employed together an average annual increase of about 21 bushels of wheat to the acre and 23 cwt. of straw over the unmanured plot, or about 1 bushel of wheat and 3 cwt. of straw over the plot treated with farmyard manure.

Other experiments, in which the proportion of ammonium salts to that of the mineral manure was larger, gave still larger amounts of increase, though at a very much diminished rate in proportion to the quantity of ammonia employed.

Nitrate of soda, taken in such quantity that the land should receive about as much nitrogen as is contained in 400 lb. of the ammonium salts, and used in conjunction with the same mineral manure as before, gave nearly as much wheat as the farmyard manure, and more straw and more total produce. Indeed, after forty years' experience, Lawes and Gilbert say that a given weight of nitrogen used as a nitrate has produced with them more growth in the wheat crop than the same weight of nitrogen used in the form of ammonium salts. This fact is of interest in its bearings on the question previously discussed, as to the equivalency of nitrates and ammonium salts considered as manures. In the earlier experiments with wheat just now mentioned, the nitrate did fully as well as the ammonium salt and it is not unlikely that it would have served a still better purpose than it did if it had been used in somewhat smaller proportion, or been applied by judicious instalments.

But as will appear directly, when the absorptive power of the soil as regards ammonia is again alluded to, ordinary field experiments are not well adapted for comparing the possibilities of the nitrates with those of the ammonium salts. A dressing of nitrate of soda might nearly all be washed out of the soil by rain, while the ammonium salt would suffer comparatively little harm. To be fair with the nitrate in any contrasted experiment, it should be applied in successive instalments; and the need of proceeding in this way is all the more conspicuous for the reason that, if too much of the

nitrate were applied at one time, the crop might run to leaf. It would be interesting, for that matter, to apply both the competitors by instalments.

How much Wheat may be got from a Pound of Ammonia?

Messrs. Lawes and Gilbert have endeavored to predict roughly how much wheat, over and above that to be obtained from the soil alone, can be got by the application to a good English soil of a given weight of ammonia. They conclude that, great as is the difference of effect of a given quantity of ammonia, according to the amount applied per acre, and according to the mineral condition of the soil and to the season, still when only moderate quantities are used, and when there is present a sufficient supply of mineral constituents, it appears that the farmer may assume, for practical purposes, that on the average of seasons he will get one bushel of wheat and its proportion of straw, beyond the produce of the soil and season, for each 5 lb. of ammonia applied as manure for the crop.

A brief recapitulation of these experimental results of Lawes and Gilbert may here be made.

On a soil of not more than average wheat-producing quality, according to the English view, which was taken for the experiments after it had supported a course of five crops subsequent to the application of any manure, wheat was grown successfully for 40 years in succession;—on some plots without any manure, and on other plots with manures of different descriptions.

Without manure, the yield of dressed wheat was in the first year 15 bushels per acre; in the 20th year, 17¼ bushels; on the average of the 20 years, 16¼ bushels; and on the average of 40 years, 14 bushels.

Mineral manures, alone, though applied in the soluble form, scarcely increased the produce. They did not, to any material degree, enable the plant to assimilate more carbon and nitrogen from atmospheric sources than it assimilated when grown upon the unmanured land.

Nitrogenized manures taken alone increased the yield of grain very considerably for many years in succession; whence it appeared that the soil subjected to the experiment was relatively much richer in available mineral constituents than in available nitrogen.

With farmyard manure, applied every year, the yield was in the first year 20½ bushels; in the 20th year, 44 bushels; on the aver-

age of 20 years, $32\frac{1}{2}$ bushels; and on the average of 40 years, $32\frac{3}{8}$ bushels.

With artificial manures, the highest produce was $24\frac{1}{4}$ bushels in the first year, and $56\frac{1}{2}$ bushels in the 20th year. Taking the average of twenty years it was $35\frac{3}{4}$ bushels, and taking the average of 32 years it was $32\frac{3}{4}$ bushels.

Of course it is not claimed that the artificial manures were applied in the very best proportions in this most interesting and valuable set of experiments. For that matter, it is not likely that the proportions were anywhere near the best. As Mr. Donald Mitchell has put it: Any bumpkin may rear a crop which shall keep him from starving. But to develop the utmost economic capacity of a given soil by fertilizing appliances, or by those of tillage, is the work of a wiser man than belongs to our day.

Experiments with rye, oats, wheat, and barley, made on a variety of soils in different parts of Prussia at the instigation of the Central Bureau of Agriculture, gave results very much like those of Lawes and Gilbert. Nitrate of soda used by itself usually gave a considerable increase both of grain and straw. But, on the other hand, mixtures of the ash ingredients of crops used without any addition of nitrogen generally gave no increase worth mentioning.

Indirect Action of Ammonium Salts.

Besides its action as plant-food, sulphate of ammonia plays an important part in the soil as a chemical agent. Like gypsum and other saline manures, it acts upon the soil in such manner that some of the plant-food therein stored up is set free and made available for the plant. It acts upon the double silicates of alumina and lime, or magnesia, or potash, in the soil, converting them in part into silicate of alumina and ammonia, while corresponding quantities of the sulphates of lime, or of magnesia, or of potash, go into solution.

Price per Pound of Ammonia Nitrogen.

Crude sulphate of ammonia is sold by the cask in our seaboard cities at from $4\frac{1}{2}$ to 5 or 6 cents the pound. It can almost always be bought in large quantities for 5 cents the pound, and often for less money. The formula of the pure salt is $(NH_4)_2SO_4$; from which, as a starting point, the percentage of nitrogen may be ascertained by a very simple sum in proportion. The atomic weights of the several elements which compose sulphate of ammonia are as follows: $N = 14$; $H = 1$; $S = 32$; and $O = 16$. Hence the

molecular weight (132) of the compound, which is the sum of the weights of all the atoms contained in it, may readily be obtained by addition as follows:

$$\begin{aligned} N_2 &= 28 \\ H_8 &= \ \ 8 \\ S \ &= 32 \\ O_4 &= \underline{64} \\ & \ \ \ 132 \end{aligned}$$

But as the molecular weight of the salt is to the weight of all the nitrogen which is contained in it, so is 100 to the percentage of nitrogen. In other words,

$$132 : 28 :: 100 : (x = 21.2)$$

These figures refer, of course, to the perfectly pure salt. But as found in commerce, sulphate of ammonia varies somewhat in quality, according as more or less moisture or other impurities are present. On the average, it contains about 20½% of nitrogen; or, speaking in round numbers, it may be said that every 5 lb. of the crude sulphate contain 1 lb. of nitrogen.

The result is thus reached, that each pound of nitrogen bought in the form of sulphate of ammonia will cost 23 or 25 cents, according as 4½ or 5 cents per pound is paid for the sulphate. This is about as cheap as nitrogen can be bought nowadays in the form of ammonia. Formerly, nitrogen of analogous quality could be had for less money in Peruvian guano; and the price of sulphate of ammonia was dependent for many years upon the price of guano. It is still true, to a certain extent, that the price of guano regulates that of the sulphate; if the price of guano were to rise, that of the ammonium salt would rise also.

A somewhat similar remark will apply to the cost of nitrogen in the form of nitrate of soda, though of late years this kind of nitrogen can usually be had at a lower price than that in sulphate of ammonia.

Price of the Pound of Nitrogen when bought in Nitrate of Soda.

The composition of nitrate of soda is as follows. The formula of the salt is written $NaNO_3$, and the atomic weight of sodium (Na) is 23. Hence,

$$\begin{aligned} Na &= 23 \\ N \ &= 14 \\ O_3 &= \underline{48} \\ & \ \ \ 85 \end{aligned}$$

and $$85 : 14 :: 100 : (x = 16.47).$$

The commercial salt is seldom, if ever, perfectly pure. It may be assumed to contain 95% of the pure salt on the average. Hence,

$$100 : 95 :: 16.47 : (x = 15.65).$$

That is to say, the crude salt will contain 15.7% of nitrogen, and to get a pound of nitrogen about 6½ lb. of the salt will be needed, for

$$15.7 : 100 :: 1 : (x = 6.43).$$

If the pound of crude nitrate of soda were to cost 4½ cents, the pound of nitrogen in this form would come at 29 cents. But of late years the price of nitrate of soda has been so low that no more than from 18 to 20 cents have to be paid for the pound of this kind of nitrogen.

Beside nitrate of soda and sulphate of ammonia, there are several other fairly good sources of nitrogen at the farmer's command, notably bone-meal, fish scrap, oil-cake, and slaughter-house refuse, as will be explained directly; and in these forms nitrogen may be procured at somewhat lower cost than it can be bought in sulphate of ammonia. But it is still true that there is no fertilizer which, in a given weight, can supply more nitrogen to crops than sulphate of ammonia, and that there are few sources of nitrogen that can be handled and transported to great distances so conveniently, so safely, and so cheaply, or which work so assuredly in field practice.

Other Salts of Ammonia.

Beside the sulphate, the salts of ammonia that specially interest the agriculturist are the carbonate and the humate.

The carbonate is formed abundantly during the putrefaction of nitrogenized substances of vegetable or animal origin, and is consequently a constituent of many kinds of manure. It is a substance of pungent odor, which, when perceived in horse stables and cow stalls, is commonly called "ammonia," for short.

But carbonate of ammonia is readily converted into humate of ammonia by contact with vegetable mould, or with the humic acid which is formed during the slow fermentation of barnyard manure; whence it follows that humate of ammonia, rather than the carbonate, may be actually concerned sometimes in the business of supplying plants with food.

Carbonate of ammonia is formed in processes of distillation, as well as in those of putrefactive fermentation. It is by distilling the nitrogenized substances coal and bone, that all the commercial compounds of ammonia, excepting Peruvian guano and some small

parcels of carbonate and sulphate from putrid urine, are obtained. Even the chloride of ammonium, often found about volcanoes, seems to be derived from the distillation of organic matters in the soil. The original "sal-ammoniac" came from the distillation of camel's dung. The ammoniacal liquor of the gas-works contains carbonate of ammonia chiefly, as well as some sulphide and sulpho-cyanide; and so does the much more concentrated distillate from bones, which is obtained as a product incidental to the manufacture of bone-black.

It is worth noticing that, as regards coal, distillation is the only known means of rendering the nitrogen available for plant-food. Neither fermentation, nor composting, nor treatment with acids or alkalies, has any effect upon this most refractory form of nitrogen. It is different as regards the nitrogen in bones, and in fish or flesh, which can readily be changed by fermentation. So too in respect to vegetable matters and peat, fermentation is a valuable means for improving the nitrogen that is contained in them. These substances, and the changes they undergo when they decay in the soil or in a compost heap, will be treated of hereafter. Peruvian guano also, which is an important source of ammonia, will need to be discussed by itself.

Phosphate of Ammonia and Magnesia.

Another compound of ammonia that has a certain interest for the agricultural student is the phosphate of ammonia and magnesia. This difficultly soluble compound is actually employed sometimes as a manure, for it must often be formed during the fermentation of dung and urine, and, for that matter, within the soil. Large crystals of it, an inch or two long, have in fact been found in the soil of some of the old German cities, where the contents of privies had been allowed to soak into the soil for centuries.

This double phosphate is specially interesting to the chemist, since it offers one of the few known means of bringing ammonia into the insoluble condition. At the same time, it enables the analyst to collect phosphoric acid from exceedingly dilute solutions, such as sewage water. Several chemists have urged that a good part of the phosphoric acid and ammonia in the urine which now runs to waste from cities might be saved by precipitating it with some cheap magnesium salt. Unfortunately, however, in order to gain any advantage in this way, the urine must be putrid; and this condition is manifestly inadmissible in densely populated places.

If sulphate of magnesia, for example, is added to fresh urine, there is no precipitate, and no apparent reaction of any kind. It is only after the mixture has stood for several days, until fermentation and the formation of ammonia have set in, that the liquid becomes cloudy through separation of the insoluble double phosphate of magnesia and ammonia. Once formed, this precipitate has great fertilizing power, as has been shown by numerous experiments on a comparatively large scale.

Amount of Ammonia in the Air.

Much labor has been expended in past years on experiments relating to the amount of ammonia in atmospheric air. A great deal has been written upon the subject, moreover, and it was at one time held by some chemists that plants derive nearly all their nitrogen from this source.

With the increase of knowledge, however, the subject has lost much of its interest. It is now known that the amount of ammonia in the atmosphere is exceedingly minute. It is in fact far too small to have much influence upon the growth of plants. About one part of ammonia in fifty million parts of air may be assumed to represent the average proportion, though the amount is liable to large fluctuations.

Many wrong notions regarding the amount of ammonia in the air have obtained currency through the false interpretation of experiments made upon the air in and about houses and cities. The very first observations that were made forcibly illustrate this point. Thus, Scheele, towards the close of the last century, argued that there must be ammonia in the air because a coating of some salt of it was formed around the mouths of bottles containing acids which were kept in his house. Not many years later, De Saussure noticed that crystals of ammonia alum separated from a dish of sulphate of alumina that had been left uncovered; whence he too immediately inferred the presence of ammonia in the air.

These observations, it will be noticed, were strictly correct. There was ammonia in the air in both these cases, but there is no longer any reason to doubt that there were local emanations of the gas which produced the observed effects; and a precisely similar remark will apply to many later experiments, where no sufficient care was taken to allow for and avoid special or accidental sources of ammonia.

At first thought, it would seem as if a great deal of ammonia must

necessarily be contained in the atmosphere. For carbonate of ammonia is not only rather easily volatile of itself, but it is readily taken up with the aqueous vapor formed by the evaporation of water, and may so be carried into the air. It is noteworthy that in the evaporation of water, as in the distillation of water, any carbonate of ammonia which may have been held dissolved escapes in the gaseous form with the first portions of the aqueous vapor. In recovering ammonia for manufacturing purposes from its solution in water, it is noticed that practically the whole of it goes forward in the first fifth of the distillate. Brustlein kept a soil that contained 0.067% of ammonia 43 days in a dry place, with but trifling loss of the gas. But on moistening and drying some of the same earth three times, half its ammonia evaporated.

Moreover, carbonate of ammonia is generated incessantly upon the surface of the earth. Wherever vegetable or animal remains decay, in the quick way, there carbonate of ammonia is set free. It is to be presumed that many a decaying leaf or worm may contribute its share of ammonia to the sum total, as well as the bodies of the larger beasts that sometimes offend our nostrils. It is known, too, that a great deal of ammonia must be thrown into the air during the combustion of nitrogenized substances, such as wood and peat and coal; for such combustion is ordinarily greatly complicated by processes of distillation. But, upon the other hand, most soils have the capacity of absorbing ammonia freely and readily, and of holding it rather forcibly. Hence the gas generated in processes of decay or putrefaction has usually but little chance of escaping into the air. Besides, carbonate of ammonia is readily soluble in water, and is consequently washed out of the air into the soil by every fog, dew, or rain. It is absorbed by the leaves of plants also, as has been said, so that, if any large amount of it were to escape from the restraining influences of the soil and the atmospheric waters, it would soon be removed from the air by the action of foliage.

A moment's consideration of these facts teaches that the question of atmospheric ammonia differs materially from that of carbonic acid. In the case of carbonic acid, a comparatively large proportion of the gas is maintained in the atmosphere by virtue of constant and abundant supplies through processes of decay, combustion, and animal respiration. But as regards ammonia, the forces which absorb and withdraw the gas are in excess of those which produce it.

Direct experiments by Boussingault have shown that atmospheric ammonia has little or no influence upon the growth of plants kept beneath a glass roof, so as to be sheltered from dew and rain, and the fact is now familiar to investigators occupied with experiments in sand or water culture.

The amount of ammonia brought down by rain, however, is often large enough to be of some scientific interest. Fresh rain-water may contain from one to three millionths of its weight of ammonia; fog and dew, from two to six millionths; and snow and hail, about as much as rain on the average.

Those portions of rain that fall at the beginning of a storm or shower generally contain a larger proportion of ammonia than those which fall subsequently. The first portions of water wash the layer of atmosphere between the cloud and the earth, and collect almost the whole of the ammonia that was contained in it. The rain that falls afterwards merely dilutes the ammoniacal solution first obtained. Towards the close of a long-continued rain the water that falls is wellnigh absolutely free from ammonia.

The rain-water collected in cities contains far more ammonia than that which falls in the country: as much as thirty parts of ammonia in a million parts of water have been observed. It has sometimes been noticed, also, that the amount of ammonia in rain may be comparatively large when the rainfall occurs after long-continued dry weather.

In the year 1855 Mr. Lawes erected a large rain-gauge at Rothamsted, having a surface of $\frac{1}{1000}$ of an acre, and the waters collected in it have been analyzed from year to year, and even from day to day at times. Warington has recently reported that the average amount of ammonia nitrogen in the water of this rain-gauge is about 0.3 part in 1,000,000 parts of water. But the amount of ammonia varies widely in the waters of different showers, so that the amount of ammonia nitrogen ranges from 0.043 to 5.491 parts to the million.

Warington computes that about 2½ lb. of nitrogen in the form of ammonia fall upon an acre of land in one year at the locality in question. In addition to the ammonia nitrogen, about a pound falls as nitric acid and another pound in organic combination, making all together about 4½ lb. of nitrogen to the acre.

Earlier observations, obtained by rather less accurate methods of analysis, gave larger amounts of ammonia. Thus Way, in 1855,

found 7 lb. of ammonia to the acre, and, in 1856, 9½ lb., in the waters of the Rothamsted gauge, which amounted to rather more than 600,000 gallons each year. German observers obtained in their turn 6⅓ lb. and 9¾ lb. of ammonia in yearly rainfalls of 400,000 and 500,000 gallons. Goppelsroeder at Basel got 7½ lb.

How Important for Crops is the Ammonia of the Air?

Some highly interesting calculations have been based upon the foregoing results; or rather upon the total amount of assimilable nitrogen, including both ammonia and nitrates, that is brought down annually upon an acre of land in the atmospheric waters. The average of a dozen different experiments made in various places and years gives 8¾ lb. of assimilable nitrogen in the water that falls on an acre. But since the average amount of nitrogen taken off from an acre of land by various crops is known with tolerable accuracy, it would seem to be no very difficult matter to decide whether the assimilable nitrogen brought down from the air could by any possibility be sufficient to supply the crop with this article of food. It appears, in fact, that the nitrogen thus derived from the air is much less than the amount consumed by ordinary crops. Thus Boussingault weighed and analyzed all the crops from a five years' rotation, and found that the following quantities of nitrogen were taken from each acre of land.

Year.	Crop.	Pounds Nitrogen taken from the Acre of Land.	
1st	Potatoes		41
2d	Wheat grain	23	31
	Wheat straw	8	
3d	Clover		75
4th	Wheat grain	29	50
	Wheat straw	10	
	Turnips	11	
5th	Oat grain	21	26
	Oat straw	5	
Sum of the five years			223
Average of each year, almost			45

Whence it appears, that under this system of cultivation nearly 45 lb. of nitrogen were taken off the land each year in the crops, or more than five times as much nitrogen as ordinarily comes to the acre of land in the rain.

But, on the other hand, if the nitrogen of the rains and snows and dews is contrasted with the amounts of nitrogen contained in those quantities of various fertilizers which practice has proved to

be sufficient to insure a good crop upon an acre of land, it will seem at first sight as if the atmospheric supply were by no means insignificant.

Thus, as Johnson has urged, Chincha Island guano and nitrate of soda each contain about 15% of nitrogen. Hence 58 lb. of either of these fertilizers would contain 8¾ lb. of nitrogen, or, as was just now said, as much as falls upon an acre of land in a year. But a dressing of 112 lb. of nitrate of soda to the acre has been known in England to double the grass crop. In most cases, 200 lb. of good guano to the acre is esteemed to be sufficient, and 400 lb. to the acre is a large application.

Still, it must be remembered that a large proportion of the atmospheric ammonia, etc. is brought down during the winter months. The experiments and the averages just now mentioned relate to the entire year. But only that portion of the nitrogen which is retained by the soil or the crop can be accounted useful; and during the winter months little if any of it can be thus retained in our climate. Hence, after all, it would appear that the amount of assimilable nitrogen derived from atmospheric ammonia and nitrates is wholly insufficient for the growth of crops. Manifestly the force of the argument is much increased by the recent experiments of Warington, which indicate that hardly more than half as much nitrogen as has here been assumed really comes to the land in the yearly rain.

Plants get their Nitrogen from the Soil.

It is to the soil that the farmer must look for the chief supply of nitrogen, as well as for all the other kinds of plant-food, excepting oxygen and carbonic acid. Most of the nitrogen of the soil exists there in insoluble and inert forms, which have never been accurately studied. They will be discussed more in detail in another place. A little of the soil nitrogen is in the form of nitrates, as was stated in the preceding chapter, and a still smaller proportion is found to be in the condition of ammonium compounds. Generally speaking, no more than a minute proportion of ammonium compounds can be detected in ordinary soils, but the fact that any ammonia can be found there is important, and many experiments have been made to determine how widely the proportion of it may vary at different times and in different soils.

Contrary to an old belief, which was founded on imperfect experiments, it is now known that ordinary soils usually contain no more than 0.0002 to 0.0008%, say 0.0006% on the average, of ammonia.

Rich garden soils may contain some 0.002%, while rich alluvial tropical soils have shown 0.004 to 0.009%. In a sample of peat, Boussingault found 0.018% of ammonia, and in leaf-mould from South America 0.05%, as was previously stated.

It seems strange at first, in view of all the ammonia which may be formed in the soil by processes of decay and fermentation, that so little of it is commonly found there; and the more especially since, with the exception of mere sands, most soils can absorb and hold considerable quantities of ammonia both by mechanical and by chemical means.

Reversion of Ammonia Nitrogen to Inert Forms.

There are at least two reasons why ammonium compounds do not accumulate in the soil; viz. their easy conversion to nitrates, as has been explained; and, secondly, their conversion into organic substances such as exist in humus.

It is known that ammonia gas and the vapor of carbonate of ammonia can be absorbed physically by soils and other porous substances, notably by charcoal and peat, by mere force of adhesive attraction, and that the ammonia thus absorbed can slowly enter into chemical combinations in the soil. It is known also, that some of the ammonia in ammonium salts, such as the sulphate for example, can combine with the hydrated double silicate of aluminum and lime, and so be "fixed" in the soil in a difficultly soluble condition, much in the same way that potash, magnesia, lime, and other bases can be fixed. When a dilute solution of sulphate, carbonate, chloride, or even nitrate of ammonia, is allowed to percolate through a column of loam, it will be found that much of the ammonia is retained in the earth in a manner analogous to that in which potash is retained when potassium salts are thus filtered through earth, or lime when lime salts are thus treated.

In addition to the hydrated silicates which take part in the fixations just described, there are various organic substances in the soil, such as, in default of any precise knowledge as to their chemical composition, are commonly classed together as "humic acids," and with these compounds ammonia as well as other bases, such as potash, lime, magnesia, soda, and oxide of iron, or the like, can enter into combination to form double humates which are well-nigh insoluble in water. Simple humate of potash, or humate of soda, or humate of ammonia, is readily soluble in water. But the double humates of potash and lime or iron oxide (or some

other base), or of ammonia and lime, or other base, are hardly at all soluble.

It will be noticed that this power of the double humates to fix soluble bases is a general fact, almost as important in its bearings as the analogous power of the double silicates. But with regard to their influence upon the amount of ammonia in soils, it appears that the complex compounds of humic acid, ammonia, and metallic oxides which result from this kind of fixation slowly undergo such changes in the earth that the ammonia in them ceases to exist as such, and is converted into a nitrogenous substance, or substances, which are insoluble in water, and of comparatively little direct value for feeding plants. As yet, the inert nitrogen compounds which result from this destruction of ammonia are not to be distinguished from those naturally contained in humus. They will be considered more particularly in connection with humus. It may be said here, however, that there are to-day few agricultural problems of more importance than the question how to devise ways and means of making the inert nitrogen compounds of the soil readily available for the support of crops.

It should be said, moreover, that several laboratory experiments have been tried by chemists, by means of which ammonia may be made to undergo changes analogous to those just suggested. Thus, when ammonia-water is strongly heated in contact with starch, or grape-sugar, or dextrin, or when it is left to act for a long time on cane-sugar at the ordinary temperature of the air, the ammonia appears to be destroyed or decomposed, while several new substances, rich in nitrogen, are formed by the union of some of the constituents of the ammonia with some of those of the starch or sugar.

There is consequently nothing forced in the supposition that either ammonia or carbonate of ammonia in the soil, or ammonia which has been fixed there as a silicate or a humate, may be radically changed by long-continued contact with the organic matters in the soil; and experiments made by Knop have shown, in fact, that when ammonia is kept during several summer months in closed vessels in contact with peat or with soils rich in humus, the ammonia actually disappears either wholly or in good part. And since, in these experiments, there was not enough air in the vessels to supply as much oxygen as would be needed for changing the ammonia to nitrates, the inference is that the ammonia was changed to

some kind of an organic substance analogous to those ordinarily contained in humus.

Little or no Ammonia in Well-water.

It is a curious fact, that, because of the power of the soil to absorb and fix ammonia, and because of the easy conversion of ammonium compounds to nitrates, hardly a trace of ammonia can be detected, ordinarily, in the soil below the depths reached by the ploughshare. It is not ammonium salts that are found in the waters of country wells and field drains, but the nitrates of lime or soda into which the ammonium salts have been converted by oxidation through ferment action. At the worst, as in city wells, a nitrate of ammonia will be found, and not chloride or sulphate of ammonium. It is in the form of nitrates, and not as ammonium salts, that the assimilable nitrogen of soils is washed out.

It is not to be understood, however, that the compounds first formed by the combination of ammonia or ammonium salts with the constituents of the soil are totally insoluble in water. On the contrary, it has been shown repeatedly, by experiment, that most of the ammonia absorbed by a given small sample of soil may be washed out again by water if the water be applied speedily. Much water is required, it is true, and the washings must be many times repeated. In other words, the compounds of ammonia formed at first in the soil are not absolutely insoluble, although they are very difficultly soluble. It is of interest to know that in the beginning they are soluble enough to be fed upon by plants.

But, after all, this washing out of ammonia from a soil is possible only as a laboratory experiment. It could hardly be done in a field, for by experiments made in fields it appears that the proportion of ammonia removed by several washings is small as compared with that retained by the soil; and that the power of soils to absorb ammonia from solutions of its salts is greater than the power of water to redissolve it. Hence the farmer need have no fear that heavy showers of rain will remove much ammonia from his land, not even when he has just been strewing guano or sulphate of ammonia. With nitrate of soda the case is different. Here there would be risk of loss if the rain were long continued; and no matter what form of nitrogenized fertilizer has been applied to the land, a small proportion of it will be found leaching away all the while in the soil-water or the drain-water, in the form of nitrates.

Not all the Nitrogen in Manures applied is recovered in the Crops grown.

Experiments made in England to determine how much of the nitrogen that is applied as manure can be recovered in the crops indicated that, under the conditions of the trials, no more than a third or a half of the nitrogen applied to the land was recovered in the crops; and it was found that a part of the waste depended upon the incesssant leaching away of soluble nitrates, into which the ammonium compounds or other nitrogenized fertilizers had been converted by fermentation and oxidation.

Amount of Ammonia obtainable from Coal.

As has been said, the ammonium compounds procurable in commerce have, with hardly an exception, been derived from coal. But the amount of nitrogen in coal is very small. It varies from a mere trace to perhaps a little more than two per cent in exceptional cases. Probably it does not exceed three quarters of one per cent on the average, and even of this small proportion only about a third passes off in the form of ammonia when the coal is distilled. Nevertheless, the manufacture of gas is conducted on so vast a scale that very large quantities of ammonia are obtained in it. For example, considerably more than a million tons of coal are distilled every year for gas in London; and it has been computed that, if the ammonia due to one third of the nitrogen in this amount of coal were converted into chloride of ammonium, as much as 10,000 tons of this salt could be got every year from the gas-works of that single city.

It has been estimated that, in the year 1883, 6,500,000 tons of coal were distilled in England, and that more than 745,000 tons of ammoniacal liquor were produced, from which 60,000 tons of ammonium sulphate might have been made. Much coal is distilled in France also, and in Belgium, and special care seems to be taken in Belgium to save the ammonium products. In Germany, in 1883, 1,516,000 tons of coal were distilled at gas-works, and some 152,000 tons of ammoniacal liquor were produced.

Ammonium salts, prepared from gas liquor, are necessarily somewhat costly, because of the labor and fuel which have to be expended in order to bring the contents of the liquor into merchantable shape. Hence, no little thought has been given at one time or another to the discovery of new sources of ammonia, as well as to the possibility of manufacturing ammonia from atmospheric nitrogen.

There are several sources of waste of ammonia, which may one day be checked. In countries devoid of anthracite, vast quantities of coal are distilled simply for the sake of the coke which is left as the residual product of the distillation. This coke is used for generating steam, for smelting metals, and in general as an excellent kind of fuel. But until comparatively recently, enormous amounts of ammonia were allowed to go to waste from the coke ovens, together with the other products of the distillation. So also, vast quantities of ammonia are lost in the refuse of cities. A noticeable quantity of ammonia that had already been manufactured has been lost in the making of ammonia alum also.

Efforts have been made from time to time to diminish the waste from these sources, and as regards the coke furnaces these efforts appear to have been fairly successful. Small amounts of ammonium products may, perhaps, still be made also from the refuse of some European cities, where the lack of an abundant supply of water prevents the use of water-closets, and permits, or rather compels, the collection of human excrements.

Soot.

The soot deposited in chimneys leading from fires where bituminous coal or wood is burned, contains small quantities of ammonium and potassium compounds and phosphates, and has long been esteemed in England as an excellent top-dressing for young grain and for grass. It is applied at the rate of from 40 to 60 bushels to the acre. Beside acting as a stimulant to excite the growth of the plants, it is said to destroy slugs and worms, and to be obnoxious to rabbits and other vermin.

Payen and Boussingault found 1⅓% of nitrogen in coal soot and 1¼% in wood soot. Breunlin found 1.31%, 2.05%, and 2.46% of nitrogen respectively in soot from wood fires, coal fires, and fires of mixed wood and coal. He found also 23.80, 24.77, and 24.75% of ashes in the soots. These ashes contained fine clay, ashes that had been drawn up the chimneys, and traces of gypsum. He found neither phosphoric acid nor alkalies in the soot from the wood fire. But Braconnot in his day reported 0.2% of acetate of ammonia, 4.46% of acetate and chloride of potassium, and 1.50% of phosphate of lime in soft soot from wood fires. Voelcker found 3½% of ammonia, 2¾% of alkali salts, 11% of carbonate of lime, and 2% of carbonate of magnesia, in a sample of commercial soot.

A sample of Belgian soot gave Petermann 2⅓% of nitrogen in the

form of ammonium salts, and $\frac{3}{4}$ of one per cent of phosphoric acid. Pavesi found in Italian soots $1\frac{1}{3}$ to 2% of nitrogen, and 1 to $1\frac{1}{2}$% of carbonate of potash. Both these observers remark on the difficulty of obtaining pure soot that has not been mixed with earth or with coal ashes.

It is to be noted that, by means of reducing agents, ammonia could be made from nitrates and nitrites in case these substances should ever become much cheaper than they are now. Ammonia could be made also very cheaply from organic matters rich in nitrogen, such as leather scraps, for example, by distilling them together with a mixture of caustic lime and caustic soda. So far from ammonia becoming more costly in the future, it is probable that it may remain at its present price for many years to come, even if the price is not diminished.

CHAPTER XIII.

OTHER ASSIMILABLE NITROGEN COMPOUNDS BESIDE AMMONIA AND NITRATES.

THE question will naturally be asked, What other chemical substances beside ammonium salts and nitrates are capable of supplying nitrogen to plants? The answer is, that experimenters have been able to grow plants by means of urea, uric acid, leucin, tyrosin, glycocoll, hippuric acid, guanin, creatin, asparagin, and acetamid. Several of these substances, it is true, are mere chemical rarities, but others are of great agricultural importance since they occur in urine and in the dung of birds. An account of them will be found in "How Crops Feed," page 293.

It has been urged at one time or another, that perhaps all these complex nitrogenized substances are really converted into ammonia or nitrates in the soil before the plant consumes them; and there may be something of truth in the suggestion. But as regards urea at least, it has been proved that this substance does not readily decompose in the soil either to form ammonia or nitrates. It has been found, in fact, unchanged in plants that have been fed with it. Uric acid also is a substance not easily decomposed. It is known,

moreover, that urine may be kept fresh for a month or more by mixing it with clay. The clay seems to absorb and remove the substances that ordinarily occasion the fermentation and putrefaction of urine, and the destruction of the urea which it contains. Hence the suggestion that urea may sometimes remain undecomposed in the soil for an appreciable period.

As against the supposition that the substances now in question are changed to ammonia or to nitrates, it is to be remembered that the experimenters who have most carefully examined the subject were themselves convinced that plants can be nourished directly by several of these compounds, particularly by urea, uric acid, guanin, and creatin.

The practical significance of the inquiry is very great. New light has been thrown upon a mass of farm experience by the evidence thus presented that urine may as well be used as a manure when fresh as after it has been fermented, and that the uric acid in guano acts directly as plant-food. Formerly it was thought by some persons that fresh urine is of little or no use as a fertilizer. They maintained that the nitrogen in urine is incompetent to feed plants before the urea has fermented, and so changed to carbonate of ammonia. It is plain enough now, however, that it may often be good practice to add preservative agents and germicides to urine, with the view of keeping its urea intact. It is an old custom in some parts of Switzerland to add copperas (sulphate of iron) to the pits or cisterns in which dung liquor collects, and it has been proved by Schattenmann in France that the practice has considerable merit. This custom has often been explained as if the sole object of it were to change the volatile carbonate of ammonia to the non-volatile sulphate, but it is not improbable that the copperas actually preserves the urine, and enables the peasants to bring a good deal of urea directly to their fields.

One peculiarity of urea, as contrasted with the carbonate of ammonia into which it changes when fermented, needs to be kept in mind; viz. that urea is not absorbed and fixed by the soil as the ammonium compounds are, and that it soaks into the land in all directions to the very great advantage of the plants that are growing there. For aught that is now known to the contrary, it is barely possible that in times of prolonged rain some urea may even be washed out of the soil, and go to waste with the excess of the ground-water, as the nitrates do, though in most cases the urea

would doubtless be changed to a nitrate before passing off in this way.

Peruvian Guano.

Next in order comes the consideration of various substances, capable of supplying either ammonia or nitrates, which are used as manures. First among them is guano, a substance which has exerted a marked influence upon the development of scientific agriculture.

True guano is a substance found upon certain rainless islands off the coast of Peru, which has resulted from the slow decomposition of the dung and other refuse of sea-fowls. As first imported to Europe and this country, some years since, it consisted to the extent of almost one half its weight of soluble ammonium salts, viz. urate, oxalate, and phosphate, together with a little sulphate and chloride of ammonium, and compounds of ammonia and fatty acids. It is to these fatty acids rather than to ammonia that the peculiar odor of guano is to be attributed.

The percentage of nitrogen in Chincha Island guano ranged from 10 or 11% in the lower grades to 16 or 17% in the best kinds, say 12 to 13% in guano of average quality. Nearly one quarter of the weight of the guano was phosphate of lime, equivalent to some 10 or 12% of phosphoric acid; and beside these ingredients there were small quantities of potash salts, a little sand, and organic matters. All this (and much of what follows also) refers to guano from the Chinchas, which has now become in some sort historic since the supply has been practically exhausted. The Peruvian guano which is procurable nowadays comes from other groups of islands, and is distinctly inferior to that which was formerly exported.

Composition of Guano.

In 1885, Wolff gave the average percentage composition of the guanos then procurable, as follows, excluding non-essential matters.

	Water.	Organic and Volatile Matter.	Nitrogen.	Phosp. Acid.	Potash.	Lime.
"Peruvian" . .	15.0	42.0	7.0	14.0	3.3	12.6
Guanape . . .	21.6	36.3	9.3	13.4	3.7	11.3
Ballestas . . .	22.9	42.0	12.2	13.1	2.8	10.5
					And Soda.	
Pabillon de Pica .	6.2	48.8	9.2	13.5	8.4	13.7
Punta de Lobos .	14.3	42.8	8.3	13.4	7.3	12.8
Huanillos . . .	10.0	40.9	8.0	15.0	6.8	14.6
					Potash.	
Saldanha Bay . .	12.2	35.5	9.0	9.2	1.3	7.6
Ichaboe, recent .	16.0	29.5	8.0	11.3	0.8	21.0

As tested at the New Haven laboratory in recent years, the composition of guano as procurable in New York, may be set down at nearly 8% of nitrogen, 12 to 15% of phosphoric acid, and 2 or 3% of potash. But there are said to be reasons for believing that the material now sold as guano sometimes consists of real guano admixed with sulphate of ammonia, and possibly with other materials. If this be so, it can no longer be said of the guano now procurable that it possesses the same peculiarities and excellences which characterized the guano of thirty years since. It is not only a weaker, but it may be a sophisticated material, the price of which is out of proportion higher than that of the guano which was formerly so much esteemed.

Nitrogen is the most important Constituent of Guano.

It is to the nitrogenized compounds in guano that its value is to be chiefly attributed. Of course the phosphate of lime has a certain significance, and it is a real significance. Were it not for this ingredient, guano could never have been used as it so often was, as a general manure. As it is, guano contains both the ingredients, viz. nitrogen and phosphoric acid (not to mention the small amount of potash), which are most needed by good soils. Land of fair quality, such as is found in many parts of Europe, may be perfectly well manured with guano alone year after year, just as it could be manured with farmyard manure. As long ago as when guano was first imported into Europe, it was noticed that it served an admirable purpose on strong clay soils.

But it is important to avoid a prejudice, at one time not uncommon, that phosphate of lime is the chief ingredient of guano. If this were so, the cheap phosphatic guanos of Baker, Jarvis, and Howland Islands, from which almost everything but phosphate of lime has been washed out by rains, would be better than the guano of Peru; whereas the fact is, that, after years of practical experience, the phosphatic guanos are used only for making superphosphates; they are nowadays rarely, if ever, applied directly to the soil. Phosphatic guanos may be bought for $18 or $20 the ton, while Peruvian guano costs $50 or $60, or more.

The fact that guano may often do good service as a general manure, because it contains both nitrogen and phosphoric acid, together with a little potash, is well illustrated by the following statement of Boussingault. He observed along a great extent of the coast of Peru, that the soil, which consists of quartzose sand admixed with

clay and is perfectly barren of itself, is rendered fertile, and made to yield abundant crops, by the application of guano, and irrigation. He says that the change produced there by such manuring is immediate and very remarkable.

Like nitrate of soda and sulphate of ammonia, guano is a manure of quick action, tending to develop rapid growth of the leafy parts of plants. Hence it is commonly used in small quantities, and as an adjunct to barnyard manure. All that has been said of the good effects of ammonia or nitrate of soda upon lands that have long been tilled will apply to guano with equal or even greater force, for in guano we have not a single salt, but a mixture of several salts; it contains phosphate of ammonia, urate of ammonia, and oxalate of ammonia, beside free uric acid and a little guanin.

Guano on Young Grain.

One merit of guano, that it assures a good start to the seedling crop, has often been insisted upon. Not only is a strong and vigorous young plant better able to withstand drought and bad weather, but it will, as a rule, suffer less from the attacks of insects, and will the sooner be able to gather within itself a store of food fit to carry it happily forward through the subsequent stages of development. Light top-dressings of guano have often been found to do much good upon grain-fields that had suffered during hard winters. Guano may be used also in this way to bring forward any patches of grain or grass which are more backward in early spring than the rest of the field.

Starting with land which is in good heart, the efficiency of guano as compared with that of barnyard manure of good quality is estimated by Stoeckhardt to be in the proportion of 1 cwt. of guano to 65 or 70 cwt. of the barnyard manure. Manifestly, the difference in the time and labor required for the handling of these two quantities is a point worth considering.

Formerly 200 lb. of the original guano to the acre was an ordinary dose. 400 lb. were thought a large application even when no other manure was used, though quantities larger than this were sometimes applied. If more than 500 lb. to the acre of such guano had been used, the vegetation would probably have been too coarse and luxuriant. Grass or grain thus heavily guanoed would have been almost sure to "lodge." The late Professor Norton, of Yale, recorded a case where 8 cwt. of the best guano were applied to an acre of turnips; the plants all grew to tops, and produced no bulbs,

and even the succeeding crop of wheat was so rank that the grain was miserable.

The guano of to-day is said to be used in England at the rate of from 3 to 5 cwt. to the acre, but twice these quantities are said to be sometimes used hereabouts by market gardeners. In general, the best way of using guano appears to be at the rate of 2 or 3 cwt. to the acre, together with half the usual quantity of barn-yard manure. In the damp, cold climate of Scotland, guano has been found to do good service upon turnips, and on strong land as much as 3 to 5 cwt. of it are often used there upon early turnips and upon other roots, without any other manure. But for late sown turnips such large dressings of guano are thought to be too stimulating; they are apt to make the crop run to leaf, so that for this case superphosphate is preferred to guano. When used for winter grain, it is said to be well to apply one hundred-weight of guano when the seed is sown, and two hundred-weight in the spring at the time when the field would naturally be gone over with a smoothing-harrow to break the crust.

It is well to bury Guano.

Several experimenters have urged that guano should be ploughed under, or harrowed in deeply, as soon as may be practicable after spreading it, and the need of so doing points clearly to two of the modes of action of guano; viz. that it helps to ferment the humus of the soil, and that the urate of ammonia in it is peculiarly useful for feeding plants. But if this urate were left at the surface of the land, it would quickly change to carbonate, and some of this carbonate would exhale. On the other hand, if the guano were but slightly buried, its nitrogenous constituents might speedily be converted to nitrate, and this change is not desirable, as will be shown in another place.

According to Hellriegel, while it is undoubtedly of great importance in dry years that guano should be ploughed under in order that its best action may be assured, there is no need of burying it deeply in wet years. Indeed, in years when moisture is abundant, guano may do better service when it has merely been worked into the soil than if deeply buried. Stoeckhardt's experiments upon the burying of guano are given in the following table. The figures relate to the weight in pounds of the sheaves obtained from one square rod (Saxon). The guano was applied at the rate of 1½ cwt. to the Morgen (= 0.631 acre).

	Winter Wheat.	Winter Rye.	Oats.
Harrowed in with the seed	7¼	6¼	21
Ploughed in to depth of 2 to 4 inches	7½	6¼	21
Ploughed in to depth of 4 to 6 inches	11¾	5¾	22¼
Ploughed in to depth of 6 to 8 inches	13¼	7¼	23

After effect noticed in a second year: —

	Oats.	Winter Rye.	Winter Barley.
Harrowed in with seed	11¼	9½	3
Ploughed in to depth of 2 to 4 inches	10¼	10	4¾
Ploughed in to depth of 4 to 6 inches	13¾	11	6
Ploughed in to depth of 6 to 8 inches	14¼	12	8¼

Heiden tried experiments with barley on a sandy loam. His results show that 1 cwt. of guano ploughed under did as much good as 1½ cwt. applied as a top-dressing. His results are given in the table below.

	Guano on Morgen (= 0.631 Acre).	Crop on Morgen. Grain.	Straw and Chaff.
No manure	...	500	847
As a top-dressing	1 cwt.	545	873
Ploughed in	1 "	669	980
As a top-dressing	1½ "	570	976
Ploughed in	1½ "	685	1257

Guano fails on Dry Land.

Of course, the supposition is in all cases that the land to which guano is to be applied is adequately supplied with water. If there is a lack of moisture, the components of the guano will not dissolve, ferment action cannot occur, and comparatively little effect will be produced by the manure. In dry seasons, guano is apt to disappoint expectations, and in this country there is a certain prejudice against it on that account. From the first, European experience has taught that guano is not so supremely excellent on light soils as on clays and on good moist loams. In order to see what guano will do when the conditions are really favorable, we have only to look at the results which are obtained with it every day by greenhouse men upon their potted plants. Every one who has systematically fertilized plants with guano admixed with water, i. e. who has applied it frequently by small portions, in presence of an abundance of moisture, knows what an admirable fertilizer it really is. In field culture, the most decided effect of guano will be seen in the first year, if the season be at all favorable; but after the second year, its effect is hardly perceptible.

Care necessary in applying Guano.

Before scattering guano upon the land, it is well to mix it with 2 or 3 times its bulk of earth, some say with 5 or 10 times its bulk of earth. The earth should be freshly dug, so that it may be somewhat moist, and the guano, which has previously been reduced to a homogeneous powder by sifting and threshing the lumps upon a barn floor, should be thoroughly mixed with the earth by shovelling the mass over and over repeatedly. The purpose of the admixture with earth is not only to insure an even distribution of the fertilizer upon the land, and to check the volatilization of ammonia, but to prevent the possibility of the guano's injuring any of the young plants or seeds. Guano is so rich in ammoniacal salts that it might burn and destroy the roots of young plants, if much of it were brought into immediate contact with them, especially if the ground happened to be dry.

For the same reason, it is well enough to strew the mixture of guano and earth two or three days before planting, and to plough or harrow it in; or the land may be rolled when the guano is sown, and the seed be harrowed in afterwards in due course. It is well, also, to apply guano during or just before rain. In the case of potatoes to be planted in hills, a handful of a mixture of guano and much earth may be thrown into the hill at the moment of planting, or, perhaps better, the ordinary mixture may be distributed along the furrow in which the hills are to be made.

These particulars were formerly much insisted upon, because of the corrosive character of this essentially chemical manure, and of the prejudice which, singularly enough, existed against it.

Guano may spoil in Damp Air.

It is to be observed that, although guano suffers but little loss so long as it is kept dry and away from the air, it may rapidly depreciate by keeping in damp air. Krocker has noticed that guano may lose from $\frac{1}{8}$ to $\frac{1}{4}$ of its ammonia during a single winter when moist air is allowed to have access to it. The moistened urate of ammonia changes to carbonate, and the latter exhales. So too the admixing of guano with earth, as above described, may hinder, but does not wholly prevent, the volatilization of the ammonia. The escape of the latter is still readily perceptible when guano is mixed with 5, 10, 20, or 50 parts of loam. According to Nesbit, even 1,000 parts of earth do not wholly prevent the volatilization.

These experiences are analogous to the results obtained by Brust-

lein in methodical experiments on the removal of ammonia from soils by means of currents of air and by the evaporation of water. Brustlein found, for example, that much of the ammonia which had been absorbed by a soil from ammonia-water escaped again easily when the soil was exposed to the air, and especially when the soil was repeatedly moistened and allowed to dry. He found also, on passing a current of mixed ammonia gas and air through a considerable amount of earth, that although most of the ammonia was absorbed by the soil, yet on passing a stream of pure air through the soil thus charged with ammonia most of the latter left the soil and passed off with the air.

Guano and Common Salt.

When guano first came into use it was a not uncommon practice to mix it with common salt before applying it to the land, and excellent results were often obtained by so doing. For example, Heiden mixed an excellent guano that contained 14% nitrogen and 13% phosphoric acid with an equal weight of salt, and manured therewith a sandy loam that had not been manured for six years, upon which he grew barley. His results are here given: —

	Crop on a Morgen (= 0.631 Acre).		Increase over no Manure.	
	Grain.	Straw, &c.	Grain.	Straw, &c.
No manure	500	846	...	...
110 lb. guano	669	980	169	134
110 lb. guano and 110 lb. salt	752	1281	252	434

It was thought at one time that the salt acted to fix ammonia and prevent it from volatilizing. But it is now known that this supposition was erroneous, and that no ammonia is fixed by the salt, in a strictly chemical sense. Probably, the salt acts as an antiseptic to hinder the decomposition of urate of ammonia in the guano, so that more of the urate is available as such for crops when salt is used.

Genuine Guano could be bought formerly.

Another point to be noted is that the manner in which guano was imported into this country, and sold here, long afforded an excellent guaranty of its genuineness. In several of the Atlantic cities there were responsible agents of the Peruvian government from whom guano could be purchased in full confidence that the fertilizer received was what it purported to be.

For many years Peruvian guano was the cheapest source of active nitrogen at the farmer's command, and until a comparatively recent

period the price of nitrogen in guano remained practically in accord with its price as contained in sulphate of ammonia and even in nitrate of soda. For example, a sample of Peruvian guano examined some years since by Prof. Johnson at New Haven was found to contain 8¾% of nitrogen and 14% of phosphoric acid. The price of this guano was $70 the ton. In a ton of the material there were 175 lb. of nitrogen and 280 lb. of phosphoric acid. The phosphoric acid was at that time regarded as worth 6 cents a pound. Hence there was $6 \times 280 = \$16.80$ worth of this constituent in the ton, and by subtracting this value from $70, the price of the ton of guano, there is obtained $53.20 as the price of the 175 lb. of nitrogen in the ton. But $\$53.20 \div 175 = \$0.30$, as the price of the pound of nitrogen, and this was precisely the rate at which nitrogen could be bought in the form of sulphate of ammonia, at the time the analysis in question was made.

There was really, however, a slight advantage in favor of the guano, for it will be observed that in the foregoing estimate the 2% of potash that was contained in the guano has been neglected. The 40 lb. of potash in the ton at 4½ cents the pound would be equal to $1.80, and if this sum be brought into the account we will have $\$70 - (16.8 + 1.80) = \$51.40$, as the price of the 175 lb. of nitrogen. But $\$51.40 \div 175 = 29$ cents, as the price of the pound of nitrogen.

It is no longer true that guano is sold at cheap rates, as compared with other fertilizers. Of late years nitrate of soda has been sold at very low prices, and the price of sulphate of ammonia has sympathized with that of the nitrate, while the price of guano has been fixed by the Chilian government at comparatively high figures. In the spring of 1885 guano that contained 7½% of nitrogen, 12% of phosphoric acid, and 2% of potash, was held at $65 the ton in New York by the agent of the Chilian government, although nitrogen in the form of nitrate of soda and of sulphate of ammonia could then be had at rather less than 18 cents the pound.

In Europe it has been customary to neglect the potash when estimating the value of guano, for the alleged reason that most soils good enough to bear the application of guano already contain considerable quantities of potash. Besides, a good deal of potash is supplied to the land in the barnyard manure that is usually employed in conjunction with guano. Perhaps the fairest way of considering the potash is as something "thrown in" and "given to

boot," which shall lead the farmer sometimes to give the preference to guano rather than to sulphate of ammonia, in case the price of nitrogen were the same in both. A somewhat similar remark will apply to the 2 or 3% of soluble phosphoric acid usually present in guano. For since soluble phosphoric acid may be estimated to be worth about twice as much as ordinary insoluble phosphoric acid, it is not fair to allow only six cents a pound for the whole of the phosphoric acid of the guano. Whence it again appears in respect to the guano above mentioned, that at $70 the ton it was a cheaper source of nitrogen than sulphate of ammonia at 6 cents the pound, or than nitrate of soda at 4½ cents.

Dung of Poultry.

The dung of fowls is a manure somewhat analogous to guano, though far less valuable than guano weight for weight. To begin with, the food of hens, of pigeons, and even of turkeys, except in grasshopper season, is of vegetable rather than of animal origin, while the sea-fowl that produced the guano lived upon fish, and consequently voided a more highly nitrogenized excrement, and moreover the guano has become highly concentrated by the peculiar processes of slow decay to which it has long been subjected. But it is none the less true, that, while the pound of guano at 2½ cents is one of the cheapest manures the farmer can buy, it does not become him wholly to neglect the droppings of his hen-roosts. Analyses show that the following percentages of substances are contained in the fresh dung of

	Fowls.	Pigeons.	Ducks.	Geese.
Water	56.00	52.00	56.60	77.10
Organic matter	25.50	31.00	26.20	13.40
Nitrogen	0.80–2.00 say 1.60	1.25–2.50 say 1.75	1.00	0.55
Phosphoric acid	1.50–2.00	1.50–2.00	1.40	0.54
Potash	0.80–0.90	1.00–1.25	0.62	0.95
Lime	2.00–2.50	1.50–2.00	1.70	0.84
Magnesia	0.75	0.50	0.35	0.20

Boussingault found in a specimen of dry pigeon dung 8⅓% of nitrogen. It contained 9½% of water also (see below). A Belgian farmer has computed that a pigeon yields about 6 lb. avoirdupois of dung in a year, a hen about 12 lb., a turkey or a goose about 25 lb. each, and a duck 18 lb.

Allowing 18 cents for the pound of nitrogen in this form, 6 cents for the pound of phosphoric acid, and 5 cents for the pound of potash,

100 lb. of hen manure will be worth some 30 or 40 cents. It is possible, indeed, as will be shown more particularly under the head of Composts, that the dung of fowls is really worth more to the farmer than these figures would indicate; for when used as a ferment, there is no telling how many pounds of inert peat a single pound of hen manure may convert into an active fertilizer. Since hen dung is apt to be sticky when fresh, and lumpy when dry, it is not particularly well fitted to be used as a concentrated fertilizer, and it may consequently well be relegated to the compost heap, as a general rule. It is to be observed, however, that much of the nitrogen in the dung of birds is in the form of uric acid, — a substance directly assimilable by plants, and easily converted into oxalate of ammonia by putrefaction.

Pigeon Dung formerly Important.

Pigeon dung, and the dung of other domestic birds, played an important part in Roman husbandry,[1] and in that of several Eastern nations, notably Persia and Egypt. Until a comparatively recent period, it was much thought of by European agriculturists also. Previous to the French Revolution, great dove-cotes were attached to the establishments of all large land-owners. It may be said of it emphatically, that it is a manure of historic importance. Since the discovery of guano and the diffusion of correct information concerning the use of nitrates and of ammonium salts, the dung of land birds is no longer of much economic importance, but the old use of it may still serve to teach a valuable lesson as to the significance of active nitrogenous fertilizers, while it illustrates the conspicuous merit of uric acid almost as well as guano does, although as was said, the dung of fowls and pigeons really differs very considerably from guano in that it has never been concentrated, and so to say purified, by the slow processes of fermentation to which the guano beds have been subjected. Pigeon dung continues to be used in Egypt and Persia to the present day, as travellers tell us.

The dung of poultry is liable to suffer much injury from fermentation and from becoming flyblown (see Bussey Bulletin, I. 24). Pigeon-dung, in particular, often consists largely of inert matters, such as the husks of oats. I have noticed samples of pigeon dung that must have been wellnigh valueless because they were composed almost wholly of broken cherry-stones (Bussey Bulletin, II. 324).

[1] See, for example, the references given by Heiden in his "Düngerlehre," II. 243.

A quantity of pigeon dung, imported into England from Egypt some years ago, contained 6¾% of water, 60% of organic matter, 21½% of sand, 3¼% of nitrogen in organic combination, 1½% of ammonia, 8% of phosphates of lime and magnesia, and ½% of alkali salts. Wein found in pigeon dung taken from a church steeple 11% of water and 89% of dry matter. The dry matter contained 56% of organic and volatile matters, and 33% of ashes, 2¼% of nitrogen, 2% of phosphoric acid, and 5½% of potash.

Dung of Bats.

In many hot countries the dung of bats collects in caves in such considerable quantities, often to a depth of many feet, that attention has repeatedly been called to it as a source of fertilizing matters. This bat guano varies widely, both as to appearance and chemical composition, according as it is more or less contaminated with dirt and has been more or less exposed to oxidation and chemical action. Voelcker and other analysts have found that it may contain of moisture, 7 to 64%; organic matter and ammonium salts, 6 to 65%; phosphoric acid, 1½ to 25%; nitrogen, ⅓ to 9%. It often contains nitrates, even as many as would represent 2 or 3% of nitric acid (N_2O_5).

Guano gave a great Impulse to Agriculture.

There are several points of general interest with regard to guano that bear so closely upon the laws of political economy and of social progress that they deserve to be taken to heart. From what has been said of the price of guano as compared with that of other manures, something may be inferred as to the enormous influence which this price has exerted, and still exerts, in regulating the price of all kinds of fertilizers. But this point is a trifle in comparison with other considerations. For the bringing of guano into the markets of the world, even more than the introduction of crushed bones, gave a very powerful impetus to the progress of intelligent agriculture.

Before the introduction of these concentrated manures, the farmer had little or no freedom of action. He was almost wholly dependent upon his barnyard for supplies of plant-food, and in all old countries at least he was tied hand and foot by a more or less complicated course of rotation of his crops. If he had money enough, he could indeed buy food for cattle, and so increase his stock of manure; and he could also employ ameliorating agents, such as lime and marl and gypsum, or he could buy a little ashes

or soot on occasion. But all these things were bulky, and difficult of transportation. Much labor had to be expended in handling them. It was wellnigh impossible for the European farmer to act upon the maxim of the nimble penny which is so characteristic of modern civilization, or to carry on his estate as if it were a manufactory. In case he had forecast a market, as a merchant would, the farmer was wellnigh powerless either to grow or to force a special crop to meet this market. If, for example, he saw evidence that barley would be in demand next year, he could not profit by this knowledge, nor by any special sagacity of this kind, unless, indeed, he should leave his legitimate business and become a trader, that is to say, a speculator in the produce of his neighbors.

By means of guano and tile drains this state of things was completely changed, and the so-called high farming became possible in Europe. There was developed an enlightened system of agriculture, which prospered during many years in England, Scotland, and Germany,—a system of agriculture, namely, which was governed by business rules and habits of thought, and which depended on capital as well as upon labor. Very soon after the introduction of guano into those countries it was found, as Stoeckhardt has formulated the matter,—

I. That by means of this manure the most fruitful fields might be excited to yield still larger crops;

II. That the regular courses of rotation might be broken in upon without harm on an emergency, and that consequently a much larger proportion of land could be given over to the growth of any crop, for which a special demand was anticipated, than was possible before;

III. That any field which might happen to fall behindhand, as regards its fertility, could quickly be brought up to its normal condition; and

IV. That growing crops, or patches of crops, that had suffered from drought or from cold could often be saved by a timely application of it;

V. That new fields could soon be brought to a high degree of fertility; and

VI. That the number of cattle kept upon a farm could either be diminished, in case the conditions were favorable for such diminution, or largely increased, by virtue of the increased yield of forage due to the use of guano. Of course, where the stock of cattle was

thus increased, the yield of stable manure was increased in a like proportion.

But when the farmers had learned that through the use of guano all these things were possible, it was but natural that they should be ready and eager to welcome other concentrated manures. Hence the easy introduction of nitrate of soda, of sulphate of ammonia, of the superphosphates, and more recently of fish scrap, flesh refuse, and potash salts. So too with regard to the desire for knowledge as to the action and the management of the concentrated manures.

Peruvian guano is no longer the only artificial manure (so called), nor the most important; but it is none the less a fact that the influence exerted upon human activity and intelligence by the introduction of guano into commerce has not been confined to the farm alone. This influence is felt to-day wherever agriculture is taught. It is to be seen in the schools and colleges, as well as in the books and newspapers that relate to husbandry. Singularly enough, the influence of guano is felt also in the conduct of those municipal and domestic affairs which bear upon the health and comfort of large populations. It is safe to say, that, were it not for Peruvian guano and the lessons it has taught, the whole modern system of cleansing cities by means of water-closets and quick-flowing sewers could never have become so general as it now is.

Under the head of Sewage, it will be seen how it is that cheap guano, and the other concentrated manures which have succeeded it, have in some sense compelled the cities to wash their filth into the sea. That is to say, the commercial fertilizers have as good as destroyed the old agricultural demand for the comparatively costly and less efficient night-soil.

As an example of the kind of feeling which was excited by the use of guano in Europe soon after its introduction to that country, may be cited the argument offered by Lord George Bentinck at a debate on the repeal of the corn law, held in the English House of Commons in the year 1846. According to Lord George, 2 cwt. of Peruvian guano applied to an acre of wheat land give an average increase of rather more than 9 bushels of the grain, at which rate a hundred thousand tons, or two million cwt. of this fertilizer, would add more than nine million bushels to the crop, or bread enough for the support of a million of people for a year. Or, for the sake of being perfectly sure, he would allow 3 cwt. of guano to the acre as necessary to produce the extra 9 bushels of wheat.

In like manner, as regards turnips, experience, he argued, had shown that 2 cwt. of guano will add 10 tons per acre to the crop. Or, if we say 3 cwt. guano, then 2,000,000 cwt. of the fertilizer would add 6,666,660 tons to the natural unmanured product of the English turnip-fields. But a ton of Swedish turnips, he maintained, will last 20 sheep 3 weeks, and each sheep should gain half a pound of meat a week, or a pound and a half in three weeks, so that the 20 sheep would make 30 lb. of mutton; and by multiplying this factor into the sum total, he naturally suggests an enormous amount of meat.

The foregoing figures, as regards wheat, differ so little from those proposed by Mr. Lawes (5 lb. NH_3 for 1 bushel of wheat), that it seems not improbable that one of the two computations may be merely a modification of, or perhaps a refinement upon, the other.

Rectified Guano.

In recent years a very considerable part of all the guano that is sold has been treated with sulphuric acid before reaching the consumer. The idea originated on treating some cargoes of guano that had been damaged by long-continued contact with sea-water, with the view of selling the product as superphosphate of lime. But the fertilizer thus prepared gave such excellent results in the fields, that much first-class guano has ever since been similarly treated with the acid. Moreover, the importers appear to be glad of the opportunity, which this process of manufacture affords, of mixing cargoes of high-grade guano with those of low grade. They are thus enabled to sell always a product of one and the same standard character and composition. Sometimes, indeed, they appear to add more or less sulphate of ammonia to increase the percentage of nitrogen. In this country, guano which has been thus treated with sulphuric acid is known as "rectified guano." It is usually guaranteed to contain 10% of ammonia (NH_3), say 160 lb. N to the ton; 10% of soluble phosphoric acid, say 200 lb. P_2O_5 to the ton; 2% of potash, say 40 lb. K_2O to the ton. At 20, 10, and 4½ cents respectively, these constituents would be worth \$32, \$20, and \$1.80; or, all together, nearly \$54 for the ton.

CHAPTER XIV.

NITROGENIZED ANIMAL AND VEGETABLE REFUSE.

Fish Scrap.

Of late years very considerable quantities of valuable nitrogenized manure have been procurable in commerce under the name of fish guano, or fish scrap, or fish waste.

There are two principal kinds of fish guano, viz. the Norwegian, which is supplied to the European markets, and the American, which is made and used in this country. The Norwegian article is to all intents and purposes dried fish, desiccated codfish so to speak, only that it contains more bone than ordinary dried fish, since it is prepared in some part from the heads and bones that accumulate as refuse in the places where fish are cured.

The American fish guano, on the contrary, is a product obtained incidentally in the manufacture of oil from a coarse sort of herring, called the menhaden, or pogy (Alosa menhaden). In order to get their oil, the pogies are boiled in water to a sort of porridge or thick soup, which is pressed in a mill, just as ground apples are pressed in the manufacture of cider. The oil that was contained in the flesh of the fish collects upon the surface of the expressed liquid, while the half-dry pomace, or residue left in the mill, is the fish scrap, — "pogy chum" the fishermen call it. Sometimes this product is pressed into barrels at once for transportation, though more commonly perhaps it is left in loose heaps to heat and to dry out to a certain extent. Occasionally the pomace or chum is spread out upon platforms to dry pretty thoroughly, and is afterwards ground in a mill. Sometimes fish scrap is dried artificially, and ground; the product being sold as "fish guano."

In accordance with these different modes of treatment, the amount of water contained in the products varies widely. Sometimes there is no more than 8 or 9 or 10 or 12% of water, while some samples of the scrap contain from 18 to 22%. Occasionally 30 or 40, or even 50% of water, is met with in fresh scrap.

These materials have hitherto been used for the most part by manufacturers of fertilizers for mixing with superphosphates, and

the value of the scrap is commonly estimated solely according to the amount of nitrogen contained in it, which usually ranges from 6 to 8%. But the percentage of phosphoric acid is nearly as high, viz. 6 or 7%.

An analysis, by Arendt, of Norwegian fish-scrap gave of

	Per cent.
Moisture	17
Nitrogen	10½
Phosphoric acid	4
Organic matter	72
Ashes	11

Other samples have shown more phosphoric acid (13 to 15%), and less nitrogen (8½ to 9%). Some of them were of scrap that had been steamed to remove the oil.

Fish Scrap a very Cheap Manure.

American fish scrap, such as that above described, is an extremely cheap manure. It can usually be bought at wholesale for $12 or $15 the ton, and seldom or never costs more than $18. At these rates its fertilizing constituents come at very low prices, the nitrogen in particular costing less per pound than so good an article can usually be bought for in its other forms. The reason why this is so appears to depend on the rather unpleasant odor of the fish scrap, which creates a prejudice against it in the minds of common carriers, and so hinders the transportation of small parcels of the material. In case the scrap costs $15 the ton, and that a ton contains 120 lb. of phosphoric acid, the value of this constituent will be $6, if we allow 5 cents for each pound of it; so that, even if there be no more than 120 lb. of nitrogen in the ton, this constituent will be worth ($15 — $6 =) $9. That is to say, the pound of nitrogen will come at 13 cents. It would probably be fairer, however, to call each pound of phosphoric acid worth 6 cents, and to argue that the material contained 7% of nitrogen instead of 6%, as in the foregoing calculation.

Fish Scrap should be used as such.

There can be no question that farmers should buy this cheap material directly from the fishermen, and use it as such, i. e. under its own name, instead of paying a comparatively high price for it, as is now often done after it has been admixed with superphosphates. I have myself found fish scrap to serve extremely well, as a substitute for barnyard manure, when used in conjunction with wood ashes or other potassic fertilizers.

Worth of the Nitrogen in Fish Scrap.

It is to be observed, however, that the nitrogen in fish scrap, though often held by dealers to be worth 18 or 20 cents the pound, or as much as the nitrogen in nitrate of soda, is really much less valuable for the farmer, at least here in the Northern States. In our climate, the chief part of the fish scrap does not act so quickly as the nitrates; more or less time is required in order that it may ferment, and that its nitrogen may thus be converted into ammonium salts or nitrates, or some other product assimilable by plants.

There is usually a small proportion of ammonia in the scrap, it is true, at the moment when it is applied to the land, though not much. On the other hand, there is no evidence that all the nitrogen in the scrap ever becomes available for plants in any climate. Herein is a great difference between true chemical compounds, like ammonium sulphate or like nitrate of soda, — each particle of the nitrogen of which is excellent, and as good as any other particle, — and organized substances, such as fish, or flesh, or vegetable matters, some of the nitrogen in which may indeed easily become available for feeding plants, while other portions are always liable to remain totally unfit for this purpose.

Recent experiments by S. W. Johnson have shown that a larger proportion of the nitrogen in freshly cooked menhaden is in an easily soluble and decomposable condition than of that contained in the dried and ground product sold as "fish guano." Indeed, ordinary menhaden scrap, as obtained from the fishermen, is better in this respect than the more thoroughly dried product. The process of drying appears in some way to impair the solubility of the nitrogen in the scrap.

It is noticeable that in the American fish-scrap a more considerable part of the value may be credited to phosphoric acid than is the case with the Norwegian product. Thanks, moreover, to its mechanical condition, and to the fact that it has been cooked, it appears to be a manure of rather quicker action than the Norwegian scrap.

As with the meal of steamed bones, so with fish; it is a reasonable inference that their flesh may act more quickly as a manure after having been cooked. This fact appears to have been enforced by some field experiments made by Heuser, who applied steamed and plain Norwegian fish scrap to a strong, well-drained, but raw and crude loam, from which the surface soil had recently been removed. The crop was barley, and it grew much more luxuriantly

where the steamed scrap had been applied. Heuser argues that the advantage lay in the easier decomposition of the steamed product, and not in any superiority as regards the amounts of nitrogen or phosphoric acid contained in it. There were harvested from the hectare the following crops, in kilos: —

	Grain.	Straw.
No manure (mean of two plots)	709	3,799
Plain fish guano	1,297	4,367
Steamed fish guano	1,704	5,032

The difference in composition between the Norwegian fish guano and American pogy scrap is readily explained by a reference to the facts that the two products are derived from different kinds of fishes, and that in the American method of manufacture the fish are boiled and pressed. Much nitrogen is of course lost in the watery liquor or soup which is pressed out with the oil. The menhaden is a very bony fish withal, whence the high percentage of phosphoric acid in the American product.

Norwegian Scrap is now made in this Country.

Fish manure similar to the Norwegian article is even now manufactured to some extent here in New England, and the amount could undoubtedly be largely increased if there were any quick demand for the finished material. Thousands of tons of worthless fish are captured every year at the fishing stations, that is to say, fish like whiting, skates and sculpins, dog-fish and other sharks, which have no merchantable value, to say nothing of good fish that become tainted in hot weather, or of the waste portions — heads, fins, entrails, and bones — of cod, haddock, halibut, and the like. It is neither a difficult nor a costly matter to dry and grind these waste fish whenever the farmers care enough for the product to make it worth any one's while to prepare it.

More than this, very large quantities of the worthless fish might readily be caught on purpose, if there were any sufficient demand for fish scrap to make them worth the catching. Those now caught are caught against the fisherman's wishes, — in spite of him, in fact. There is a never-failing supply of fish in the sea, where there is an almost infinite amount of room, and where man has small power to annihilate, or even to thin out, the migratory fishes.

There can be no doubt that in the future, when the increase of population shall enforce a more intelligent agriculture, the drying of fish scrap will become a highly important branch of industry.

It bears even now very curiously upon the question of utilizing the sewage of cities. The reproach has often been made, that the modern system of removing filth from cities by means of water-closets and sewers flowing to the ocean is wasteful, unphilosophical, and wrong. But it appears from what has just been said, that such censure is hasty and ill-considered. So long as a clean, innocuous, and concentrated manure can be got from the sea, in the shape of fish scrap, at less cost of money, comfort, labor, health, and life even than would have to be expended in transporting the city filth to the farm, or in converting it into transportable form, it would be mere folly for the farmers to waste their energies upon the sewage.

In speaking thus of "health and life," reference is had, of course, to diseases traceable to stagnant sewage, and to the various ills which may arise from the storing of excremental matter about houses, or from using it upon fields.

It is evident that, so long as nitrogen and phosphoric acid can be obtained more cheaply in the shape of fish scrap than they can be got from the filth of cities, the question of removing this filth does not even come within the domain of agricultural inquiry. It remains a civic and a sanitary question merely, and has little or no interest for the farmer.

There are localities, no doubt, as is the case with many inland cities, where the sewage must eventually be carried to the land in some way, simply because there is no other outlet for it; but the question is an open one, whether even here it may not be cheaper and better simply to filter, aerate, and methodically disinfect the foul water than to attempt to apply it for the growing of crops.

To illustrate how entirely the possibility of using any manure must depend upon the cost of getting it, it might be suggested that, beside the method just now alluded to, of drying fresh fish caught upon the spot, some system of salting those caught at a distance from the fishing towns could readily be devised, so that the factories of fish guano should be supplied from a wider area. And to this end cheap chloride of potassium from Stassfurt could perhaps be used to replace common salt, so that potash as well as nitrogen and phosphoric acid would be contained in the fish guano, which would thus become a less special manure than it now is. Indeed, fish scrap thus salted could be classed as a complete manure. But it is evident that the question whether any such plan could ever be put

in practice must depend upon considerations as to whether the product so obtained would be worth to the farmers as much as the cost of bringing it to them. The answer seems plain, that fish thus salted cannot be used as manure, because the cost of getting them would be very nearly as large as the cost of getting ordinary edible salt-fish.

Of late years, the saving of fish waste for agricultural purposes tends slowly to increase. There is a constant demand for it on the part of the manufacturers of the so-called ammoniated superphosphates and of formula fertilizers, i. e. mixtures compounded on the basis of the composition or supposed needs of any given crop. Factories of fish guano, on the Norwegian plan, were established long ago by Frenchmen on their islands near Newfoundland. There are several such factories here in Massachusetts, though the owners of some of them appear to find it more profitable to operate upon the flesh of whales than upon that of fish proper. So, too, as Nordenskiold noticed, the Norwegians bring the carcasses of whales from Spitzbergen to the guano factories on the Norwegian coast.

Krocker has analyzed whale guano, in comparison with ordinary fish guano, as follows:—

	Norwegian Whale Guano.	Norwegian Fish Guano.
Moisture	5.35	9.84
Organic and volatile matters	62.35	56.18
Ash ingredients	32.30	33.98
	100.00	100.00
Nitrogen	7.63	8.50
Phosphoric acid	13.45	14.84
Lime	16.49	15.96
Magnesia	0.15	0.94

Considerable quantities of cod and haddock scrap, and of waste fish also, are saved, however, both at the factories on Cape Cod and at Gloucester on Cape Ann. The prices of several kinds of fish waste are quoted every day in the reports of the Gloucester fish market. For example, when pogy scrap is held at $12 the ton, fish waste is cited at $9, and liver scrap at $6. This liver scrap, which is sometimes sold at $3 or $3.50 the ton at Gloucester, is the refuse from fish livers that have been boiled and pressed to remove their oil. It is a rather soft and somewhat sticky product, but is undoubtedly valuable, and very cheap at the prices last mentioned.

A sample of fish waste sold at $16 the ton at Gloucester, in 1885, contained

Water expelled at 212° F.	8.25%
Nitrogen	7.00%
Phosphoric acid	6.50%

It consisted of skins, fins, and back-bones, with more or less flesh attached, as taken from salted cod and haddock that are to be packed in boxes and sold free from skin and bone. An analogous product, as cut from half-cured fish, but not dried by artificial heat, could be bought at Gloucester, in 1885, at $3 or $3.50 the ton.

Long ago Payen and Boussingault found 6¾% of nitrogen in salted codfish that had not yet been dried and contained 38% of water; and almost 17% of nitrogen in codfish that had been washed and pressed, and dried in the air, so that it contained only 10% of water.

On the coast of Maine more or less of the refuse from herring and mackerel that are canned or packed as sardines is saved nowadays, besides great quantities of the menhaden refuse, as above mentioned.

Fish Scrap needs to ferment in the Soil.

Inasmuch as almost the whole of the nitrogen in dried fish is in the form of organic compounds, the material needs to undergo decomposition or fermentation in order to be made available as plant-food. To this end moisture, warmth, and air are necessary; and these conditions may be fulfilled by burying the fish scrap not too deeply in a mellow soil, in warm, but not too dry weather. It is claimed that, in our Southern States, fish scrap generally gives a better account of itself than it does at the North; and the idea is probable enough, because of more rapid decay to ammoniacal products there, and subsequent quick nitrification.

In view of the different climates of France and England, it was perhaps not unnatural that the French should have prepared and used fish scrap to a considerable extent some years before the English paid much attention to it. In like manner, it would appear that woollen rags were formerly held in special esteem in France, though it is true that they were freely used in some parts of England also, for certain kinds of crops.

Manifestly, it would neither be wise to use Norwegian fish scrap as a top-dressing, nor to plough it under very deeply, for in both cases the necessary fermentations would be interfered with. So too, on cold ground in early spring there would be small reason to

expect quick profits from fish scrap; but upon good corn land in warm summer weather it might do superexcellent service. Probably the best way of using fish scrap in temperate climates is in conjunction with not very heavy dressings of farmyard manure, or in conjunction with live wood ashes, if they can be got.

Fish Waste preserved by Lime.

A method of saving fish refuse by means of lime, which was employed long ago in France by Hérouard, may perhaps be worthy of being put in practice sometimes by farmers living in localities where worthless fish are obtainable at certain seasons. The plan was, to mix in a hogshead tub, layer by layer, quicklime and the offal obtained in cleaning fish. The lime will slake by virtue of the moisture of the fish waste, and at the same time the latter is said to be disaggregated. On throwing the mixture into heaps, and finally forking it over, a powdery product is obtained. Manifestly, the lime combines chemically with the flesh to form an albuminate of lime, as it were, which is a body little liable to putrefaction or change when dry. Indeed, the limed fish may be kept as well as fish that has been salted and dried.

There are several familiar examples of analogous compounds of lime and organic matter. In domestic economy, broken crockery is sometimes mended by a cement prepared from lime and milk, or lime and cheese; and there is a process of calico-printing, in which inert coloring matters are fixed upon the cloth by causing casein and lime to combine upon them to form a product insoluble in water which clings firmly to the cloth, — caseate of lime it might be called. In the making and refining of sugar also, lime is used both to clarify the cane (or beet) juice and the solutions of brown sugar; and it does so by combining with various albuminous and mucilaginous substances, which, if they were left dissolved in the juice, would quickly decay and excite the fermentation of the sugar.

The remark of Chaptal, in his Chimie Appliquée (I. 153), that lime forms insoluble compounds with almost all animal and vegetable substances that are soft, and thus destroys their power of fermenting, seems to have had no little influence in stimulating inventors to employ lime as above, and for preserving night-soil and clarifying sewage also, as will be explained hereafter.

One point remains to be noticed in respect to the nitrogenized manures other than ammonia and nitrates. A successful grower of

tobacco has informed me that he gets a better flavored leaf when he manures the plants with fish scrap, flesh, or blood, than when he uses nitrates or ammonium salts. Here is seen another reason, among many, in favor of using several varieties of manure at one and the same time.

Animal Refuse.

Beside fish scrap, there are several other nitrogenized fertilizers of importance, notably dried blood, dried flesh, and some kinds of oil-cake.

All kinds of animal refuse are highly nitrogenized, and some kinds are valuable manures. Thus, there are several matters occasionally obtainable at the farm, such as the intestines of animals, bits of skin and flesh, sinews, and the like, which are of value when properly composted with earth, and thus brought to a condition in which they can be subdivided and made available to the plant.

All the foregoing substances decompose readily in moist earth, and might be applied directly to the plant were it not for the difficulty of distributing them advantageously.

There is another set of substances, such as horn, hoofs, hair, wool, and woollen rags, bristles, feathers, and leather, which, though highly nitrogenized, decompose so slowly in the earth that they are of comparatively little value when applied directly to the land. Some of them indeed are of no value whatever. In order to derive much advantage even from the best of them, they must either be allowed to ferment in the compost heap, in contact with dung or urine, or with powerful chemical agents such as ashes, or potashes, or lime; or they may be boiled in potash lye; or any of them might be subjected to destructive distillation, either alone or admixed with an alkali, for the sake of the ammonia which could be obtained in that way as a product of their decomposition.

As several chemists have remarked with regard to leather, it is not at all strange that this substance should decompose so slowly in the soil as to be practically worthless as manure, for it is a product that has been specially and purposely prepared to resist decay.

Torrefied Leather.

It has often been thought that the fertilizing power of leather, or the like, might be improved by subjecting it to heat strong enough to disorganize it, and make it crumbly and friable, without actually destroying it. In point of fact, much leather scrap is actually treated in some such way as this for the purpose of recovering the oily mat-

ters which were introduced into the leather during the process of currying it. There is small reason to doubt withal that the powdered product has been employed sometimes for the adulteration of nitrogenized superphosphates.

As Reichardt insisted some years since, leather scraps when subjected to the action of hot steam in a close boiler become hard, dry, and brittle, and can then be readily reduced to the condition of a fine powder.

"Leather meal," prepared in this way, has been somewhat used as a fertilizer in Europe, and has been found to differ from mere powdered leather in that, as shown by experiments, it has a certain small, though appreciable fertilizing power, while the original leather has none. It appears also, from Morren's experiments, that leather meal (from steamed leather) enters into putrefactive fermentation when moistened and kept in a warm place, and evolves offensive odors. A small proportion of ammonia is produced, and considerable quantities of soluble nitrogenous compounds, though the amounts are less than those produced from torrefied horn-meal under similar conditions. These experiments consist with the experience of practical men, who much prefer the horn-meal to the leather-meal.

Instead of steaming leather scrap in boilers, Coignet, in France, has employed the cheaper method of subjecting it, and other nitrogenous matters, to the combined action of steam and hot products of combustion from a coke fire. His apparatus is so arranged that the leather (or horn, or rags, or refuse from the glue-makers) shall be enveloped during several hours by a mixture of steam and chimney air at temperatures in the vicinity of 300° F. Under these conditions leather (or horn) swells somewhat, and becomes dry and friable without losing any of its nitrogen. Petermann found 6¾% of nitrogen and 14⅓% of phosphoric acid in a sample that had been sold in Belgium as Coignet's fertilizer. It is evidently with reference to this process that the statement has recently been made, that certain manufacturers of fertilizers at Paris devote themselves particularly to the preparation of torrefied wool, horn, leather, and even bone, the latter having first been steamed strongly to remove oil and gelatine.

Morren has studied some of these torrefied products, and finds that the horn-meal speedily enters into putrefactive fermentation when kept moist. Some ammonia is produced during the putre-

faction, as well as a quantity of soluble nitrogenous products. It was found that the horn-meal decomposed much more readily than the leather-meal, and that practical men prefer it to the leather-meal as a fertilizer.

According to S. W. Johnson, leather chips usually contain 5 to 8% of nitrogen. He finds that ammonia is given off from them copiously when they are boiled in strong potash lye.

Reichardt suggested some years since, that it might be well to treat the powdered leather-meal (steamed) with a weak solution of potashes, which, as he found, is capable of dissolving nearly one third part of the steamed leather. It should here be said, that, previous to 1860, the chemist Runge, in Germany, manufactured an artificial fertilizer upon a large scale by boiling leather scraps and woollen rags with a mixture of Glauber's salt and quicklime.

Composition of Blood and Flesh.

Lean flesh contains about 75% of water, 3 to 4% of nitrogen, 0.5% of alkali salts, and 0.5% of phosphoric acid; or in a ton, say 70 lb. of nitrogen and 10 lb. of phosphoric acid. When dried in the air, Payen and Boussingault found in it 8½% of water and 13% of nitrogen.

Fresh blood contains about 80% of water, 2.5 to 3% of nitrogen, 0.5% of alkali salts, and 0.25% of phosphoric acid; or in a ton, say 55 lb. of nitrogen and 5 lb. of phosphoric acid.

Dried blood is an article of commerce. It has long been prepared in France for exportation to the sugar-growing colonies, and has commanded a tolerably high price. So long ago as 1856, Stoeckhardt told of its being sold at the rate of $3 or $3½ the hundredweight. The French method of manufacture is as follows. By coagulation, fresh blood is made to separate into liquid serum, from which albumen is prepared for use in the arts, and into a solid clot, which, when dried and ground, is the substance used as a fertilizer and known as dried blood or blood-meal.

A litre of fresh blood is said to yield about 500 grams of clot, containing 170 to 200 grams of dry substance carrying 12 to 13% of nitrogen. But in order to facilitate the drying of the clot, it is mixed with small quantities of other matters, whereby the proportion of nitrogen is reduced somewhat. As sent into commerce, the French product (dried blood) contains 13 or 14% of water; 78 or 79% of organic matter; 7 to 9% of ash ingredients; about 12% of

nitrogen; from 1 to 1⅓% of phosphoric acid; and about ⅘ of one per cent each of potash and lime.

Ten samples of blood-meal examined at the Münster experiment station contained from 8½ to 13¼% of nitrogen, or in the mean, 11¾%. Practically, dried blood is usually mixed with other fertilizers before coming to the farmer's hands.

Blood is a quick-acting manure, and one that is conveniently applied in horticulture. Highly favorable results are said to have been obtained in practice by watering young fruit trees with a mixture of fresh blood and 10 or 12 times as much water.

Field Experiments with Dried Blood.

Petermann, in Belgium, has carefully tested the fertilizing power of dried blood, as compared with that of nitrate of soda, upon spring wheat, both on a clayey and a sandy soil. The experiments were made in quantities of earth amounting to 4 kilos, and there were added to this amount of soil the following quantities of fertilizers, either one at a time, two at a time, or all three at once, as stated in the table; viz. 0.25 grm. nitrogen, 0.3 grm. phosphoric acid, and 0.2 grm. potash.

NITROGEN ALONE.

Kind of Fertilizer.	Clayey Soil. Grain.	Clayey Soil. Total Crop.	Sandy Soil. Grain.	Sandy Soil. Total Crop
No manure	7.94	26.13	2.08	7.34
As dried blood	19.56	62.07	5.05	15.75
As nitrate of soda	20.14	64.39	7.51	27.02
NITROGEN AND PHOSPHORIC ACID.				
N as dried blood	19.51	62.41	8.94	29.40
N as nitrate of soda	19.62	64.58	9.76	31.12
NITROGEN, PHOSPHORIC ACID, AND POTASH.				
N as dried blood	19.44	63.17	12.19	34.78
N as nitrate of soda	19.80	64.81	12.93	36.97

Although the nitrate of soda was superior on the whole to the blood, especially on the light land, the blood nevertheless did good service, and was decidedly better than steamed wool, as tested in previous experiments. It will be noticed that the addition of phosphatic and potassic fertilizers to the nitrogenous did no good on the clay, though such additions were of considerable use on the light land. It has been reported, indeed, that Petermann has found that the wheat crop may be doubled on certain infertile sands in Belgium by the judicious use of dried blood.

In England, blood composts are said to be excellent top-dressings

for either grain or grass, and dried blood mixed with bone-meal, or with a superphosphate, has often been found to do good service on turnips.

The nitrogen in dried blood is probably worth considerably less, pound for pound, than that in Peruvian guano, though of course it is worth very much more than that from less easily decomposable materials. In the opinion of some observers, the nitrogen in blood is worth twice as much per pound as that in coarse bone-meal.

Blood and Lime.

Any blood that happens to be at the farmer's disposal, either from animals slaughtered at the farm or as obtained from a neighboring butcher, may be put to use directly for compost making, or, perhaps better, it may be preserved by means of lime as follows. The blood is thoroughly mixed in a shallow box with 4 or 5% its weight of dry, freshly slaked lime; the mixture is covered with a thin layer of the lime, and left to itself to dry out. The dry mixture may be kept for a long while without change. It may be applied to the land as such, or it may be added to a compost heap.

To test this matter, Heiden mixed 2,000 grams of sheep's blood with 130 grams of freshly slaked lime and covered the mixture with a thin layer of the lime (1%), and he found that the mixture solidified completely in the course of 24 hours. During the months of July and August he left the mixture in a room where it was exposed to several hours' sunlight every day, but he could not perceive that it underwent any change excepting that the odor was a trifle less perceptible as time went on, and that a very hard crust formed on the surface that was not easily cut with a knife. Beneath this crust the material was less hard; it was black, and looked like undecomposed blood. Meanwhile more than half the moisture originally contained in the blood had disappeared.

Dried blood containing as much as 10 or 12% of nitrogen and from 10 to 20% of moisture may still be procured in this country as a fertilizer, though in the article commonly sold as dried blood by the dealers in manures it has been more or less admixed with other kinds of animal refuse. Indeed, it is said by some manufacturers of fertilizers, that it has been found impracticable to keep mere dried blood for any length of time unmixed; but that, when the blood is thoroughly mingled with dried pulverized meat, the two keep perfectly, with no perceptible loss of ammonia.

Chandler's Scrap.

For that matter, dried flesh, even by itself, is an article of commerce. There are several varieties of it. One product in particular, known as "greaves," or "cracklings," or "chandler's scrap," is obtained as a residuum in the rendering of tallow and the preparation of soap-grease. It consists of the membranous portion of the animal fat or suet, from which the tallow or fat proper has been separated by melting and pressing. These greaves occur in commerce in the form of large compact cakes, like cheeses, which have been pressed very strongly. Payen and Boussingault found 8½% of water and 12% of nitrogen in a sample which they examined.

Formerly it was no very easy matter to break up or pulverize one of these cakes, though by long soaking in water they could be broken down sufficiently to admit of the flesh being applied as a manure. Nowadays the cakes are made thinner and much more manageable. Greaves are said to have been used to a certain extent at one time, many years ago, by the manufacturers of superphosphates for reinforcing their products. They are used for feeding dogs in England, and poultry in this country. Sometimes they are given to swine also.

Before the cheaper kinds of slaughter-house refuse were to be had, damaged greaves offered a good material for fermenting peat in compost heaps, and they were on that account worthy the attention of farmers. But when in good condition greaves are worth too much as an article of fodder ever to be used as manure. There are probably hundreds of farmers in this country who would find their advantage in using this material for feeding hogs.

Corn-meal by itself is too starchy and too little nitrogenous to be the best possible food for growing swine; and these chandler's scraps will supply just what the maize lacks.

Flesh-meal.

Another kind of dried flesh is prepared in Germany from dead horses, and from cattle that have died of disease. It is sold expressly as a manure under the name of flesh-meal. It is a valuable product, and the process of manufacture is worthy of encouragement.

As practised at Leipsic some years ago, the mode of procedure was as follows. After having been skinned and opened, the horses were divided into four pieces, which were thrown into large iron cylinders arranged to act as Papin's digesters. Each of these cylin-

ders was large enough to receive 3 or 4 horses at once, and in these receptacles the flesh was exposed to steam for 8 hours under a pressure of 2 atmospheres.

By this long-continued steaming the whole of the fat in the carcasses is extracted, and all the tendons and sinews are changed to gelatine. Even the smaller bones of the animals are softened. When the steam is finally shut off, two layers of liquid are found in the digesters. The upper layer consists of soft fat, which has a well-established value in commerce. It is used for wheel-grease, for making soft-soap, and for preparing wool for spinning. The lower layer of liquid, on the other hand, is a soup; that is to say, it is a solution of glue contaminated with the so-called extract of flesh. It is evaporated to the consistence of syrup, and sold under the name "bone-size," to be used by weavers in preparing their thread for the loam. After the boiled flesh has been pressed, it is dried in a kiln, the bones are picked out, and the flesh is ground to powder by itself.

The factory at Leipsic had three digesters, and by working day and night could dispose of 16 or 18 horses in the course of 24 hours. Practically, it did use up some 1,500 horses, 150 cattle, and 500 hogs, dogs, and sheep, in the course of the year.

Another factory at Rheydt, in the Rhine region, worked up from 1,000 to 1,200 head of horses, and a few hundred other animals, as well as several thousands of hundred-weight of refuse from slaughter-houses, such as the head and feet of sheep. The meal from this last factory has been analyzed by Karmrodt. He describes it as a yellowish, dry, and tolerably fine powder, having a slight odor of incipient putrefaction. It contained 8.68% of N, and 7.53% of P_2O_5.

At another factory of the same kind, near Linden, in Hanover, bones and dried flesh were ground up together. Hence, a larger proportion of phosphoric acid in the meal.

From an analysis by Wicke, it appears that flesh-meal of this kind contains 6½% of nitrogen, and 30% of phosphates, which may perhaps amount to 14% or so of phosphoric acid. Hirzel found in flesh bone-meal from a factory in Munich, 7% of moisture, 7.44% of nitrogen, and 14.9% of phosphoric acid. Wolff gives for average flesh-meal, as sold in Germany, 9¾% of nitrogen, 6⅓% of phosphoric acid, and 28% per cent of water.

I have myself found 4 or 5% of nitrogen, and from 12 to 16% of

phosphoric acid in an analogous product obtained at a slaughter-house in Boston, by drying down offal composed of waste flesh, blood, and bone. The mixture is heated by steam in a jacketed iron cylinder, and stirred continually with hot rakes. Much of the phosphoric acid in this case, however, was manifestly of poor quality, because it was contained in fragments of coarsely powdered teeth.

Tankage.

Under the name of tankage, a kind of flesh-meal is prepared in this country from the refuse meat, entrails, and other offal that accumulate in slaughter-houses. These materials are steamed in tanks to remove grease, and the residue is dried down and reduced to a fine mechanical condition. When well prepared, this product should contain no more than 10 or 12% of moisture, though sometimes it has been found to contain as much as 30%. Usually it contains more water and more phosphoric acid, some 5 to 7% namely, but less nitrogen, some 7 or 7½%, than pure dried blood. Since much of the nitrogen in this material is easily decomposable, it is to be regarded as a valuable manure.

Other products from modern slaughter-houses, consisting of mixtures of blood, bone, and meat, dried and powdered, have been found to contain 5 or 6% of moisture, and 11 or 12% of nitrogen.

Large quantities of flesh-meal from slaughter-houses at Fray Bentos, in Uruguay, where Liebig's extract of flesh is prepared, have been carried to Europe, and there used both as fodder and as manure. Beside residual flesh from which the juices have been extracted, this product contains blood, bone, tendons, etc., like the other flesh-meals. Analysis shows that it contains 5 to 7% of nitrogen, and from 13 to 20% of phosphoric acid. The manufacturers claim that it contains 6% of nitrogen, and 16% of phosphoric acid.

Oil-cake.

With regard to oil-cake, it may be said that most kinds of it are worth so much as fodder that they should not be applied directly to the soil as fertilizers. But there are some kinds of oil-cake, such as those from the castor-oil bean, and from the physic-nut of the Cape de Verde Islands, which contain some purgative or medicinal principle, and are consequently unfit to be used as food for animals.

Castor Pomace.

Castor pomace is a merchantable product in this country, and the physic-nuts have often been expressed here in Boston. Castor

pomace usually contains some 5 or 6% of nitrogen, about 2% of phosphoric acid, and 1% of potash. It is said that some tobacco growers believe that castor pomace has a particularly favorable effect on the quality of the tobacco leaf, which cannot be produced by other nitrogenous manures, and that they prefer to pay a specially high price for nitrogen in this form.

As compared with other kinds of oil-cake, the value of a ton of castor pomace may be computed as follows: —

100 to 120 lb. of N at 15 cents	\$15.00 to \$18.00
40 lb. of P_2O_5 at 6 cents	\$2.40
20 lb. of K_2O at $4\frac{1}{2}$ cents	.90
Say,	\$18.00 to \$22.00

As with the other kinds of oil-cake, the large amount of organic matter contained in this material would count in its favor as against some kinds of artificial fertilizers upon gravelly soils that are not too dry.

Linseed Cake.

Linseed oil-cake usually contains about 5% of nitrogen, $1\frac{1}{2}$% of potash, and $2\frac{1}{4}$% of phosphoric acid. It is evident from these figures that it must be a much weaker manure than guano, with which it was thought worthy at one time of being compared. A ton of Chincha Island guano would have contained $2\frac{1}{2}$ times as much nitrogen, 6 times as much phosphoric acid, and rather more potash even, than a ton of oil-cake. Hence, unless the price of oil-cake were considerably less than half the price of such guano, there could be no thought of using it directly as manure.

Formerly, however, both linseed cake and rape cake were used directly as manure in Germany and in England, with excellent results so far as appearances went. It was found that the broken cake, applied at the rate of 500 or 600, or even 800 or more, lb. to the acre, decomposed readily in the soil, except in very dry seasons, so that no preliminary composting or fermentation was strictly necessary. It was often used by itself as a top-dressing for grain. But some farmers preferred to mix the broken cake with loam, and to moisten this mixture to incite fermentation, in order to be sure of quick and regular action when the material was applied to the crops.

In Flanders, the oil-cake was mixed with much liquid manure, and suffered to ferment therewith before it was applied to the land. These fermentations were doubtless philosophical enough in the

days that preceded the use of guano, ammonium salts, and nitrates; but nowadays the farmer can buy in these substances manures that act as speedily and as efficiently as the fermented cake, and which are more manageable and decidedly less troublesome. One reason why the composting was persisted in is found in the fact that heavy dressings of oil-cake, when applied at the same time with seed grain, are apt to ferment so quickly and powerfully that the seed becomes involved in the process of decay, and is destroyed.

In general, the action of oil-cake, though somewhat slower than that of guano, was found to be quicker than that of bone-meal. The following experiment of Stoeckhardt will illustrate this point. The crop was oats grown on land that was fairly moist.

	Fertilizer. Kilos to the Hectare.	Harvest. Kilos to the Hectare.	
		Grain.	Straw and Chaff.
No manure	...	928	1,213
Bone-meal	400	1,127	1,390
Bone-meal and Sulphuric acid	400 200	1,249	1,757
Rape-cake	400	1,872	2,387

On dry land there is no sense in using oil-cake anyway; and on good land, except in very dry years, the chief part of the fertilizing effect of the cake is felt during the first season. German observers have estimated the effect at 50, 30, and 20, for the first, second, and third years.

Cotton-seed Meal.

Cotton-seed also, and the cake from cotton-seed, have been largely used in this country as manures. Indeed, considered merely as a manure, cotton-seed cake is somewhat richer than linseed cake. But now that methods have been devised for removing the hulls and fuzz from cotton-seed, this cake is perfectly well adapted to be used for the fattening of cattle. Properly, it must henceforth be classed among foddering materials and not as a mere manure.

From the average of many analyses of the normal product it appears that the composition of cotton-seed meal is somewhat as follows: —

	Per Cent.
Water	8.00
Oil	13.70
Albuminous matters	44.00
Mucilaginous and saccharine matters	21.50
Woody fibre	5.70
Ash	7.10
Nitrogen, though subject to considerable variation, about	7.00
Phosphoric acid	2½ – 3.00
Potash	1½ – 2.00

It should be said, in parenthesis, that meal from undecorticated cotton-seed is still not infrequently met with. It is of darker color than the normal meal, from containing fragments of the black hulls, which can be detected on close inspection. Such meal is inferior to the normal, both as a fertilizer and as a fodder. The wellnigh worthless hulls dilute the fertilizing matters on the one hand, and on the other they make the cake less easy of digestion and less safe as a food. The fertilizing value of a ton of cotton-seed meal may be computed as follows: —

140 lb. N at \$0.15	\$21.00
50–60 lb. P_2O_5 at \$0.06	\$3.00 – 3.60
30–40 lb. K_2O at \$0.045	\$1.35 – 1.85
Say	\$25.00

By referring to the column of prices current in almost any city newspaper, it will be seen that undamaged cotton-seed meal can often be bought, even in the Northern States, for rather less money than it is worth when considered as a mere fertilizer. And it not infrequently happens that damaged lots may be got at a considerable reduction in price, so that nitrogenous manure may be had in this form at low cost. As was said, cotton-seed meal should by good rights be used as fodder. But so long as the generality of American farmers cannot see this very conspicuous fact, there is no reason why the stuff should not be used as a manure. The supply is large, and, so long as there is no more active demand for the material than now obtains, the price of it must continue to be low, — low enough to put even the sound meal in the category of cheap fertilizers.

Experience has shown that cotton-seed meal is usually as good a fertilizer, as regards its nitrogen, as either dried fish or flesh scrap, provided the land is not too dry. It is a product that should not be lost sight of by farmers who wish to buy fertilizers.

In the Southern States, much cotton-seed meal is used nowadays for fertilizing sugar-cane, cotton, and corn. It is usually applied there at the rate of about 400 lb. to the acre. Formerly, the actual whole cotton-seeds were much used as a fertilizer at the South, care being taken to kill the seeds by causing them to ferment and heat, either in the soil or in compost heaps, or simply in large piles that were kept wet.

An instance has been recently recorded of the successful use by tobacco-growers of a substitute for farmyard manure, prepared by mixing 1,000 lb. of cotton-seed meal, 500 lb. of the ashes of cotton-seed hulls, and 500 lb. of lime. This mixture was used at the rate of two tons to the acre.

Indirect Use of Oil-cake.

The composition of linseed meal is about as follows:—

	Old Process. Per Cent.	New Process. Per Cent.
Water	9.30	10.00
Oil	5.70	3.60
Albuminous matters	34.50	33.00
Mucilaginous and saccharine matters	35.40	38.40
Woody fibre	8.70	9.00
Ash	6.40	6.00

The value of this material as a fertilizer is manifest. But, as was said before, much the best way of utilizing oil-cake is to feed it out to cattle in conjunction with the rough unmerchantable fodders of the farm, and to carry to the fields the dung obtained from these cattle. On many farms in some parts of the Mississippi Valley, for example, large quantities of corn-stalks, clover haulm, and straw are produced as incidental products, which to all appearance might be fed out to advantage on those farms in conjunction with cotton-seed meal. At all events, it could hardly be advisable, on such farms, to buy phosphates, or guano, or the other commercial fertilizers.

The manure produced by cattle fed with oil-cake will contain not only all the phosphoric acid and potash of the cake, but it will be rich in nitrogen also. It will contain much more nitrogen, for example, than manure obtained from cattle which have been fed upon nothing but hay. Meanwhile the oil and the albuminous and starchy or saccharine matters in the cake will be converted into fat and flesh, or milk, or some other useful product, in or upon the bodies of the animals.

It has been noticed in the experiments of Lawes and Gilbert, that

nitrates are formed more slowly, and that they continue to be formed during a longer time, in soils which have been dressed with the manure of animals that have been fed with oil-cake or the like, than they are in soils that have been fertilized with ammonium salts. Oil-cake itself, or at the least rape-cake does not nitrify so rapidly as many other substances. This fact may be due either to the presence of matters in the rape-cake which cripple the nitric ferment, or to the fact that the nitrogenous matters in the cake change to ammonia less rapidly than do those in some other substances.

Bran and Malt Sprouts.

Of bran and malt sprouts it may be said, that they are everywhere so highly esteemed as fodders that they are seldom used directly as manures. But, like everything else, they are liable to suffer damage, and may then be usefully employed as fertilizers. Both of them contain considerable quantities of nitrogen, and they are tolerably rich in ash ingredients also, as may be seen by referring to the books which treat of foddering materials.

Wool.

Woollen rags, and powdered wool in the form of flocks, shoddy, rag-wool, and the like, have a certain not very well-defined value as manure. Early in this century, Townsend proved, by pot experiments with sand and with clay, that woollen rags greatly promoted the growth of wheat and of cabbages. He remarked that in England such rags have been found of great utility as a manure, more especially for wheat. It is a matter of practical experience, he said, that, when spread at the rate of 4 or 5 cwt. to the acre, they nearly double the crop of wheat the first year, and yield a visible increase in the two succeeding years. They were esteemed to be valuable also for barley and oats, and were used extensively upon hop-fields. But nowadays woollen rags command so high a price from the manufacturers of cloth that they have been put out of the farmer's reach. The present plan is to tear the rags to shreds, which are mixed and carded with fresh wool or with cotton, and finally spun and woven into the form of cloth. Flocks also, which is a trade name for the dust of wool, are made into cloth; or rather, the wool dust is incorporated into loosely woven woollen cloth by a process of fulling or shrinking, in such wise that the interstices are filled up, and the cloth made close and smooth and heavy, while it becomes much warmer than it was before, because less open for the passage of air.

Woollen rags were formerly of much better quality than they are nowadays, because they were then free from the enormous adulteration with cotton which now prevails among all kinds of woollen goods. When the older writers on agriculture make reference to woollen rags, they mean rags which were really composed of wool, that contained some 17 or 18% of nitrogen, whereas it might now be difficult to find such rags anywhere. As met with to-day, the rags may contain some 10 to 12% of nitrogen, or 200 to 240 lb. of nitrogen to the ton; and if it were true that this nitrogen was directly assimilable by plants, or readily convertible into ammonia or nitrates, — in other words, if it were true that rags were a quick-acting manure, like guano, — they might still be worthy the farmer's attention, even when sold at tolerably high prices. But rags are not by any means so quick acting as guano. All kinds of wool waste decompose but slowly in the soil, and it was on this account that a rule was laid down formerly that rags should be applied at least six months before the sowing of the crop they were meant to benefit.

The more finely divided the material, the more readily will it decompose in the soil, and the more evenly can it be distributed. Hence, if the amount of nitrogen contained in the materials were the same, shoddy or shredded wool would be better for the farmer than rags; and flocks, which are rags ground to fine powder, would be better still. Probably the nitrogen in rags would be worth to the farmer about 10 cents the pound. Hence a ton of rags that contained 10% of nitrogen would be worth $20; or, stated in simpler terms, woollen rags are worth about a cent a pound for fertilizing purposes.

It has been sufficiently proved by European experience that woollen rags have real merit as manure, in spite of their slowness of action. It is to be presumed that they would do better in warm than in cold climates, and on soils that are not too dry. When used by themselves in England and France, they decayed so slowly that their influence was sometimes felt during 7 or 8 years. It was held to be better, therefore, to mix them with some easily putrescible substance, like urine or guano, which should act as a ferment as regards the wool, i. e. which, while undergoing decomposition itself, should cause the wool with which it is in contact to putrefy and decompose.

In France considerable advantage is said to have been derived

formerly from rags thus used in conjunction with liquid manures. Probably it would be better to compost rags with dung even, than to apply them directly to the land.

"Wool waste" containing from 2 to 7% of nitrogen, or about 3¾% on the average, is still used in France and Belgium. It is said to be ploughed under in autumn at the rate of 1,500 to 2,200 lb. to the acre. Sometimes this waste is used as an absorbent for the liquid excrements of men or animals. An analysis of materials taken from a vault where wool waste had thus been used showed 27% of water, 2% of organic nitrogen, 1% of ammonia, 1⅓% of phosphoric acid, 1.1% of potash, and 7⅓% of lime.

Petermann's analysis of a muddy material which separates from the water in which wool is scoured, and which contains the mechanical impurities that have been removed from the wool, showed 49% water, ½% nitrogen, ¼% potash, and ⅛% phosphoric acid.

Methods of Decomposing Woollen Rags.

Mention has already been made under leather of Runge's method of decomposing rags by means of alkalies, i. e. by boiling the woolly materials with sulphate of soda and quicklime. His process was as follows: 3 lb. of quicklime, 1 lb. of sulphate of soda, and 96 lb. of water were used for every 8 lb. of the rags, and the mixture was boiled during 3 or 4 hours. In the factory, where the operation was conducted in a boiler under an extra pressure of ½ to 1 atmosphere, the decomposition of the rags was more rapid.

Manifestly an analogous process might be employed by farmers here in New England, which would consist in simply boiling woollen rags, refuse from woollen mills, waste hair from tanneries, (or bones, hoofs, and horns,) in a weak solution of potashes, or in a lye obtained by leaching wood ashes, though as a matter of course some small portion of ammonia would be evolved and lost when wool is boiled with an alkali.

Hoffmann proposed some years since to boil wool or the like in caustic lye, obtained by leaching wood ashes through lime, and to add milk of lime to the "soup." The lime would unite with the wool to form a jelly from which the revivified potassic lye could be poured off and used again and again for dissolving new portions of wool. In this way a comparatively small quantity of potash lye could be made to dissolve much wool refuse, and convert it to a fertilizer.

A process patented in Europe some years since for decomposing

woollen rags and hair, and for separating them from cotton or linen paper stock, consisted in boiling 100 lb. of the rags for an hour in weak milk of lime, prepared from 10 lb. of quicklime and 600 lb. of water, and then beating out the disorganized wool from the cotton or linen.

Another method, probably much less commendable than the use of alkalies, has been proposed by Zabel in Germany for utilizing the worn-out cloths in which beet-pulp has been pressed in the sugar-houses. He draws the cloths through pan sulphuric acid and packs them tightly together in a high heap in order to induce fermentation. Beneath this heap a quantity of waste bone-black is placed, to catch the drippings of sulphuric acid, and the heap is covered also with the spent black to the depth of a foot or more. After a few weeks the cloths were found to be completely destroyed. Possibly some such process as this might sometimes be found useful by gardeners for reducing twigs, weeds, and other rubbish to a manageable manure, though probably potashes would serve them a still better purpose.

Analyses of Hair, etc.

Payen and Boussingault found 13¾% of nitrogen in flocks of cow hair that contained 9% of moisture, and Way found 11.83% of nitrogen in refuse horse-hair that left nearly 5% of ashes on being burned. The Münster experiment station reports, in ten samples of hair, from 3⅓ to 13¼% of nitrogen, the mean amount having been 11¼%. Scherer reports 17% of nitrogen in human hair dried at 250° F. S. W. Johnson found 9⅓% of nitrogen in hair felt.

Hoffmann found 6.7% nitrogen in hair somewhat admixed with lime that was obtained from a tannery.

There is a waste product of offensive odor, called "scutch," that accumulates in the yards of glue-makers and skin-dressers which consists of a mixture of hair and other animal matters, and lime. It is esteemed as a manure after it has fermented. Way found in 3 different samples of this material 0.89, 1.35, and 1.57% of nitrogen, from 0.50 to 1.84% of phosphate of lime, and from 30 to 33% of carbonate of lime, beside 24 to 26% of water and various impurities.

In feathers, Payen and Boussingault found 15⅓% of nitrogen; and in feather dust, which appeared to consist of sweepings from a warehouse, Way found 6¼% of nitrogen. But feathers are peculiarly slow to decay.

Torrefied Wool.

Another process worth mentioning was proposed in England several years ago by Ward. In order to save the paper-stock in rags of mixed composition (wool and cotton, or silk and cotton), and the seams cut from woollen rags, i. e. seams which had been sewed with cotton or linen thread, the material was exposed to steam of from 3 to 5 atmospheres pressure during 2 or 3 hours; the wool in the rags is thus converted into a friable substance, which is easily beaten out from the unchanged cotton, and collected in the form of dust. The cotton is used for making paper, while the wool dust contains some 12% of nitrogen, and is said to be a manure of much quicker action than flocks, though less quick than guano.

Petersen has recently proved that steamed wool such as this is a fertilizer of considerable merit. He tried pot and field experiments with "wool dust made soluble with steam," in comparison with simple woollen rags, with the result that, taking the crop of spring wheat obtained on unmanured soil as equal to 100, there was gained on the average by manuring with

	Without any Addition of Phosphate.	With Addition of Precipitated Phosphate of Lime.
Woollen rags	17	19
Steamed wool	25	34
Nitrate of soda	38	38

The steamed wool did well also on sugar-beets, though not so well as nitrate of soda.

Analyses of Horn-Meal.

Payen and Boussingault found 14⅓% of nitrogen in horn shavings. Way found 12½% of nitrogen, and cites instances where horn shavings have given heavy crops of hops. Analyses of 9 samples of horn-meal made at the Münster experiment station showed 7½ to 14¼% of nitrogen, or in the mean 11⅓%. Hellriegel reports that horn-meal contains some 10 to 13% of nitrogen, and from 6 to 10% of phosphoric acid. In buffalo-horn shavings and sawdust, S. W. Johnson reports 14½ to 15% of nitrogen, and no more than 0.08 to 0.15% of phosphoric acid. Dry horn is readily powdered after having been steamed during 10 or 12 hours.

As procurable in this country, from comb manufacturers, horn waste occurs in the form of thin light shavings, which are sometimes composted with horse manure for several months before being applied to the land. Some observers have maintained that the shav-

ings are so light and bulky that they cannot be conveniently put to use upon the farm, not even when composted as aforesaid.

A German receipt directs that the fine horn be put in a pit, layer by layer, with powdery slaked lime, and that each layer be moistened with water. The horn soon becomes soft and considerably decomposed.

Value of Organic Nitrogen.

The question already alluded to, what value should be allowed for the pound of nitrogen as contained in these animal and vegetable products, is one of no little complexity. Several of the nitrogenized substances above enumerated actually vary a good deal in price, since they are put to various uses in the arts, and comparatively few irreproachable experiments have been made to test their worth as manure from the money point of view. As has been said already, it is recognized by everybody that the pound of nitrogen in bone-meal is worth much less than the pound of nitrogen in guano, and the remark is still more emphatically true of rags. Yet again, for all ordinary purposes the nitrogen in old leather is worthless, unless it be changed by distillation, or possibly by the action of chemicals, as has been suggested above. In 1866, Stoeckhardt estimated the worth of the pound of nitrogen for Saxony as follows :—

	Cents.
For easily soluble or decomposable nitrogen, as in ammonium salts, nitrates, guano, dried blood, urea, etc.	17½
For nitrogen in fine bone-meal, poudrette, etc.	15½
In ordinary coarse bone-meal, horn-meal, oil-cake, wool-dust, fresh human urine, etc.	13
In crushed bones, horn shavings, woollen rags, human excrements, dung of stall-fed cattle, etc.	9

The prices now current in this country differ much less from the foregoing than might be supposed. The nitrogen in Peruvian guano now costs about 22 cents the pound, and that in nitrate of soda about 18 cents. The pound of nitrogen in fine bone-meal is often rated at 16 or 18 cents, and that in the coarsest bone-meal at 10 cents. The pound of nitrogen in cotton-seed meal can usually be bought for 15 cents, and that in fish scrap for still less.

Experiments with Organic Nitrogen.

Experiments made in Germany by Seyffert upon kohl-rabi were so arranged that the plants should be well fed and subjected to like conditions, except that they got different kinds of nitrogenous food, as in the table.

When fertilized with	Grams of Crop were obtained.
No nitrogenous fertilizer	76
25 grams N in crude Mejillones guano	71
" " leather-meal (steamed)	469
" " steamed bone-meal	1,572
" " dried blood	1,654
" " horn-meal (steamed)	2,005
" " nitrate of soda	2,608

Whence it appeared that nitrate of soda and horn-meal were specially good, and leather-meal particularly bad. As regards dried blood, compare the results given on a previous page.

To control the foregoing results, Albert tried similar experiments with oats, as follows: —

Kind of Nitrogenous Fertilizer used.	There were harvested Grams of Grain.	Straw.	Roots.	Total Plant.
No nitrogen	5.2	15.7	14.3	35.2
Leather-meal (steamed)	13.3	22.2	13.6	49.1
Leather-meal fermented	21.5	36.4	17.2	75.1
Steamed bone-meal	36.2	41.3	20.0	97.5
Steamed bone-meal fermented	34.0	44.3	20.3	98.6
Dried blood	24.8	44.5	18.5	87.8
Dried blood fermented	29.6	57.2	16.5	103.3
Horn-meal (steamed)	47.5	70.4	25.4	143.3
Nitrate of soda	48.9	62.6	27.9	139.4
Sulphate of ammonia	33.2	44.6	21.1	98.9

Here again nitrate of soda and horn-meal did well, and fermented blood-meal also. Leather-meal was of no account, and it served no useful purpose for the crops that succeeded the oats. Even the fermented leather-meal was of but little use.

In the following trials by Eckenbrecher it would seem that the nitrogen of the blood, bone and horn were applied under conditions specially favorable for the fermentation of these substances, and for the growth of plants. The experiments were made in sterile sand contained in boxes nearly a square yard in area and rather more than a foot and a half deep. Fit quantities of the ash ingredients of plants were mixed with the sand, and each box received in addition 5 grams of nitrogen in the form of one or another of the substances enumerated in the following list. The sand was properly watered, of course, and the temperature was favorable for the growth of plants. The experiments lasted two years. The results were that the following crops were harvested from the sand admixed with ash ingredients, to which was added

	Oat Grain. grm.	Total Crop. Straw and Grain. grm.
No nitrogen	12.6	80
Blood-meal	42.2	225
Horn-meal	38.1	227
Bone-meal	47.7	249
Sulphate of ammonia	46.0	251
Nitrate of triethylamin	52.9	252
Nitrate of soda	58.3	260
Crude guano	15.5	92

The behavior of the guano is remarkable, but was not explained.

With horn-meal and bone-meal the ripening of the grain was delayed appreciably, as had previously been noticed by Albert. The good effects of triethylamin are interesting, since this substance is obtained in considerable quantities of late years as an incidental product in the manufacture of alcohol from beet-root molasses.

Tests by Way of Artificial Digestion.

Another method of testing the value of the nitrogen in organic compounds has been proposed by Stutzer and Klingenberg, viz. to subject the materials to a process of "artificial digestion." That is to say, a weighed quantity of the fertilizer is left to soak for a number of hours in a warm liquid, similar to the gastric juice of animals, prepared by mixing pepsin with diluted muriatic acid. The idea on which this method of research is based is, that those fertilizers which are most readily soluble and decomposable in the stomach, or rather those which contain the largest proportion of soluble nitrogen compounds, will be likely to do the best service in the field.

Stutzer and Klingenberg obtained the following results: —

	Total Nitrogen in the Material. Per Cent.	Of each 100 Parts of Nitrogen there were	
		Soluble in the Pepsin.	Insoluble in the Pepsin.
Blood-meal	13.54	89.75	10.25
Leather-meal (steamed)	6.91	39.19	60.81
Horn-meal (torrefied)	13.70	40.73	59.27
Horn filings (crude)	7.06	23.43	76.57
Poudrette	6.77	80.23	19.77
Poudrette (from another city)	1.58	22.92	77.08
Waste wool	10.55	2.72	97.28
Bone-meal (raw)	4.02	95.45	4.55
Ditto, another sample	3.94	97.95	2.05
Bone-meal (steamed)	4.31	92.74	7.26
Ditto, another sample	2.43	88.35	11.65
Peruvian guano, from which the uric acid had been removed	11.08	94.53	5.47
Wool that had been treated with sulphuric acid	12.37	85.34	14.66

In this country Shepard and Chazel, and S. W. Johnson,[1] have tested a variety of products by means of the pepsin process, with the following results: —

SHEPARD AND CHAZEL'S TESTS.

	Total Percentage of Nitrogen in the Material.	Of each 100 Parts of Nitrogen there were Soluble in the Pepsin.	Insoluble in the Pepsin.
Dried blood, red	15.19	99.81	0.19
Dried blood, black	14.49	78.61	21.39
Dried fish scrap	11.56	88.67	11.33
Dried slaughter-house refuse	12.84	61.29	38.71
Dried flesh scrap (excellent)	14.17	93.32	6.68
Dried king crab (shell and all)	12.15	52.10	47.90
Acidulated fish scrap	7.14	84.59	15.41
Roasted leather-meal	9.92	37.80	62.20
Cotton-seed meal	7.76	83.18	16.82
Cotton-seed meal (from which all oil had been removed)	8.56	85.67	14.33
Cotton-seed (ground)	4.23	83.10	16.90

JOHNSON'S TESTS.

Kiln-dried blood (black)	13.44	96.8	3.2
Kiln-dried blood (black)	13.47	97.9	2.1
Fish scrap (menhaden)	10.64	85.9	14.1
Fish scrap dried and ground	8.76	71.2	28.8
Dried horse-flesh	8.12	61.3	38.7
Ground bone (clean, hard, and dry)	4.11	98.8	1.2
Cotton-seed meal	6.68	92.7	7.3
Castor pomace	6.88	92.4	7.6
Maize refuse after extraction of starch	5.55	82.9	17.1
Buffalo-horn sawdust	14.85	7.2	92.8
Horn waste (shavings)	15.37	22.4	77.6
Fine ground hoof and horn	13.69	28.2	71.7
Wool waste	11.25	4.8	95.2
Felt waste	13.12	7.2	92.8
Leather fine and brittle	8.13	25.4	74.6
Leather treated by benzine process	8.40	35.9	64.1
Leather reduced by superheated steam and ground	6.85	33.3	66.7
Hair and leather mixture	6.91	13.8	86.2

In general, the foregoing results consist fairly well with what is known of the behavior of the several kinds of fertilizers in the field, though those which relate to horn-meal do not well agree with some of the results of pot experiments as given on a previous page.

Blood and bone-meal, flesh, oil-cake, and unsophisticated fish

[1] Report of Connecticut Agricultural Experiment Station, 1885, page 117.

scrap, commend themselves here as they have done in farm practice; leather-meal and wool waste exhibit their well-known inertness; while dried slaughter-house refuse and over-dried fish scrap occupy a middle place. As Professor Johnson has remarked, this process of analysis does divide the organic compounds into two classes, according to the solubility of their nitrogen. In one class more than half the nitrogen is soluble, while in the other scarcely more than a third of the nitrogen is soluble. But to this first class belong all the compounds which farm experience has shown to be generally and really useful as fertilizers.

One noteworthy item in this list of experiments is the observation that leather-meal which has been soaked in so weak an alkali as a solution of borax becomes tolerably easily soluble in the pepsin solution. A sample of leather reduced by superheated steam gave up 84% of its nitrogen to pepsin solution after treatment with borax, while only 33⅓% of the nitrogen was soluble before the borax treatment.

Distillation of Rags, etc.

A device for utilizing the comparatively inert nitrogen of rags, which was practised in a small way in Germany some years since, is worth mentioning as a matter of history. Indeed, it has recently been described anew as a method of practical merit. The rags were distilled upon the farm, and the ammoniacal fumes were collected in acid or in water. The liquid was then mixed with earth, and applied to the land. The distillation was effected in a simple chimney, about 6 feet high by 2 feet wide, built roughly of bricks. At the bottom of the chimney was an opening for the removal of ashes and the admission of air. At the top the chimney could be closed by a movable plate; and at a point below the top a knee-shaped tube led from the chimney to a series of wooden vessels charged with water or sulphuric acid, and connected with one another by means of wooden tubes.

To start the apparatus, a fire of wood was built in the chimney, and the latter was then filled with rags and closed at the top. Air enough was admitted at the bottom of the chimney to permit the lowest rags to burn slowly, or rather to glimmer or smoulder away, and so heat the rags next above them. There was thus always, from first to last, one layer of the rags exposed to a temperature high enough to effect distillation, just above the layer of rags which were actually burning. The fumes from the smouldering

rags passed over through the abduction flue into the absorbing vessels.

The apparatus was of extreme simplicity and cheapness, such as any man could construct for himself. The ashes drawn from the bottom of the chimney were mixed with earth, and were used in conjunction with the ammoniated liquor, and the whole formed an excellent manure as quick acting as guano.

It is manifest that any such operation as this would be possible only in countries where labor is cheap, or upon farms where there might happen to be occasionally labor unfit for more remunerative enterprises. It is not impossible, however, that the process might sometimes be applied with advantage in this country to mixtures of peat and old leather, or leather scrap, and occasionally perhaps to the burning of weeds, or other refuse raked up from gardens. The process is interesting from its resemblance to that by which the ammonium salts of commerce are obtained from coal; and, as has been said, coal teaches, even more emphatically than leather, that the nitrogen in organic compounds is not always immediately available as a source of plant-food. What is true of coal in this sense is true also in some degree of peat, and of vegetable mould, the black earth of ordinary soils.

Inert Nitrogen of the Soil.

As has been said already, it is a fact of deep importance that much of the nitrogen in ordinary soils exists there in an inert and comparatively useless state, somewhat analogous to that in which it exists in leather or in coal.

Not only the nitrogenized portions of plants and of dung, but even ammonia itself, appears to be changed in part in the soil into humus-like substances, many of which seem to be incapable of supplying nitrogen directly to the plant.

The humus of the soil is never devoid of nitrogen. Peat sometimes contains as much as three per cent of this element. It was at one time thought by some chemists, notably by Mulder, that this nitrogen of the soil is in the form of humate of ammonia, — it being further assumed that the humate in question is not readily decomposable by alkalies, and the other agents that destroy ordinary ammonium salts. But this view is highly improbable. It is true, indeed, that a part of the nitrogen compounds of the soil are slowly decomposed, with evolution of some ammonia, when brought into contact with lime or the caustic alkalies, and especially when

heated with these agents; but, on the other hand, they are not decomposed by the weaker alkali magnesia, though magnesia is well known to be fully competent to decompose ammonium salts.

The probabilities are decidedly in favor of the view previously expressed, that the humate of ammonia, which is known to be formed in the soil through absorption and fixation of carbonate of ammonia, soon changes to an inert nitrogenized compound of another order, which contains no true ammonia.

The fact that some kinds of peat exhale ammonia in burning, or even in putrefying, is no evidence that the peat contains ammonia ready formed, any more than the evolution of ammonia from flesh, bones, rags, coal, and many other nitrogenized substances, under like conditions, is evidence that they contain ammonia.

It may possibly be true, as Professor Johnson has suggested, that the soil nitrogen is contained in some compound belonging to the class of amids. Urea, for example, is an amid of carbonyl,

$$CH_4N_2O = N_2 \left\{ \begin{matrix} CO'' \\ H_2 \\ H_2 \end{matrix} \right. ,$$

and acetamid is an amid of acetyl,

$$C_2H_5NO = N \left\{ \begin{matrix} C_2H_3O \\ H_2 \end{matrix} \right. .$$

It is known that amids, such as leucin ($C_6H_{13}NO_2$) and tyrosin ($C_9H_{11}NO_3$), occur habitually among the products of the decay of albumen and allied substances, and there are good reasons for believing that these particular amids, and others analogous to them, though still more difficultly soluble, are formed in the soil when albuminous substances, i. e. plants and manures, decay there.

In favor of this view is the fact just stated, that a part of the humus of the soil slowly decomposes when boiled with strong alkalies, while ammonia is set free, much in the same way that the true amids are slowly decomposed with evolution of ammonia when thus treated with alkalies. It is on account of this evolution of ammonia, when loams are boiled with milk of lime, that the old statements given in the books as to the amount of ammonia in soils can no longer be accepted as strictly true.

It is important, no doubt, to know the fact that there are substances in the soil from whose decomposition ammonia can readily be obtained, and it is well to gain an idea as to about how much of the easily decomposable substances may be contained in a given

sample of earth. The error was in counting the easily decomposable matters as if they were really ammonium compounds. From the results of some of these old experiments, it seemed to appear that as much as 0.10% of ammonia might be contained in soils such as the more accurate experiments of to-day show to contain no more than 0.001 or 0.002%.

It was not until Boussingault substituted magnesia for the stronger alkalies in the analytical process of estimating ammonia, that any useful results were obtained, and even the magnesia process has been improved upon latterly. Many absurd hypotheses have been advanced on the strength of the old belief, that the nitrogen in the soil is in the form of ammonia.

It is not strange that the misconception should have arisen, for, as Boussingault has observed, the mere admixture of caustic lime with a good garden soil at the ordinary temperature is sometimes sufficient slowly to set free ammonia through the decomposition of the nitrogenized humus.

Disputes as to the Comparative Merit of Nitrogen and Ash Ingredients in Manures.

It was because of this old error that disputes arose formerly as to whether there was any use in applying nitrogenous fertilizers like ammonium sulphate or nitrates to the land. The argument was that there is plenty of ammonia in the soil already, and that consequently only ash ingredients such as phosphates or potash or lime need to be applied to the soil in order to increase its natural fertility. Some chemists even went so far as to argue that the good effects of guano are due solely to the phosphate of lime and the potash that are contained in it.

It is now known by every one that these suppositions were fundamentally wrong. In spite of the fact that there is usually a great deal of nitrogen in the soil, it is seldom that any large proportion of it is in a condition fit to be assimilated by plants. It is the business of the farmer sometimes to render the soil nitrogen assimilable to crops, and at other times to supplement it with supplies of active nitrogen brought from the farmyard or from abroad; and either the one or the other of these acts may be the more judicious according to circumstances.

As has been said already, some of the inert nitrogen of the soil is probably derived from the reduction of ammonium salts and nitrates; but it is none the less true, that most of it comes directly

from albuminoids and other compounds of nitrogen which formed a part of plants and animals that have decayed in or upon the soil. When vegetable matters, or animals, or manures that have been derived from them, undergo change in the earth, a part of their nitrogen doubtless escapes as such into the air as free nitrogen gas, a part is converted into ammonium salts and nitrates, and the remainder is left in the soil in the form of the organic compounds now under discussion, most of which are insoluble in water, and comparatively speaking inalterable when exposed to water and air.

According to Loges, a certain part of the inert nitrogenous matter in humus is soluble in muriatic acid, and appears to play the part of a weak base. He finds, at all events, on leaching loams with the acid and evaporating to dryness the liquid thus obtained, that a nitrogenous black residue is left even when soils are operated upon which contain but little humus. It is evident that this black residue must be a substance of different chemical character from the humic acids, since these bodies are difficultly soluble in muriatic acid, and only dissolve therein to the extent of faint traces. Analysis showed that a sandy soil rich in humus contained 0.804% of nitrogen, and that 0.322% of nitrogen was dissolved out of the soil by muriatic acid. In another instance, the acid dissolved 0.083% of nitrogen from a loam that contained 0.367%.

It is thought that, after the first hot fermentation has ceased, the waste of carbon and hydrogen from decaying organic matter is more rapid than the loss of nitrogen; so that the final residue or "humus" may sometimes contain a larger proportion of nitrogen than the substances from which it has been formed.

Crops use much Soil Nitrogen.

From what has been said, it follows as a matter of course that the amount of nitrogen in a soil as determined by analysis is no fair test of the power of that soil to produce crops.

On the other hand, the addition of a few pounds of nitrogen per acre to a soil, in the form of guano or of nitrate of soda, will often produce effects which are out of all proportion greater than could be produced by so small a quantity of nitrogen if it were placed upon a soil wholly devoid of that element.

Thus, as has been said, 112 lb. of nitrate of soda to the acre — a common top-dressing for grass in England — has been known to double the crop. But the 112 lb. of nitrate of soda contain no more than 18 lb. of nitrogen, while in one long ton of English hay

there are about 22 lb. of nitrogen. Hence, in case there should be obtained 2½ tons of hay from an acre of land manured with the given amount of the nitrate, 56 lb. of nitrogen would be taken off in the crop; or three times as much of this element as could possibly have been derived from the manure.

So too with guano. From 200 to 400 lb. of the variety formerly in use were commonly applied to an acre of land; that is to say, from 30 to 60 lb. of nitrogen, on the assumption that the guano contained 15% of this element. But in a ton of clover hay there is about 43 lb. of nitrogen, so that, if 2½ tons of hay were obtained from an acre, the amount of nitrogen taken off by the clover would amount to 108 lb.

There are two possible ways of explaining this lack of agreement. The argument must be, either that the crop is made vigorous enough at the start, by the guano or the nitrate, to enable it to consume the soil nitrogen to better advantage than less vigorous plants could; or, much more probably, that the guano or the nitrate bring about fermentation or other chemical or vital action in the soil which decomposes the humus and unlocks the soil nitrogen. It is known that guano contains some of the nitric ferment; and it is not improbable that crude nitrate of soda may promote fermentation.

In any event, however, care must be taken not to undervalue the soil nitrogen; for although it is, comparatively speaking, inert, it is by no means absolutely so.

Amount of Nitrogen supplied by the Soil.

Professor Thaer has recently estimated, from the results of many trials, that of each 100 lb. of nitrogen carried off the land in crops 55 lb. are derived from the soil nitrogen and 45 lb. from the manure. In special trials made to determine how much assimilable nitrogen could safely be applied as manure, it appeared that, during the eleven years of the experiment, 52 lb. of nitrogen were harvested on the average per year and per acre, while only 24 lb. of nitrogen per year were applied to the land in the manure. More than this amount of nitrogen could not be applied commonly, except at a disadvantage. Rye, indeed, bore 35 to 38 lb. of nitrogen to the acre, and oats and potatoes 43 to 52 lb., though the largest amount named did not increase the yield of potatoes. Thaer concludes that, in general, and for ordinary circumstances and conditions, about half as much nitrogen may be applied in the fertilizers as would be expected to be contained in the crop.

Mr. Lawes has frequently insisted that the farmer must not expect to obtain in the increase of a crop an amount of nitrogen equal to that supplied in the nitrogenous fertilizers put upon the land. He has dwelt at some length on the fact that, in the experiments of Dr. Gilbert and himself, where sulphate of ammonia and nitrate of soda were applied to grass, wheat, oats, and barley, not much more than half the nitrogen supplied to the land was recovered in the first crops taken after the manuring, regard being had, of course, to the increase of crop over and above what was obtained when fertilizers were used that contained no nitrogen, but only ash ingredients.

He remarks, incidentally, that it is by no means certain whether as much nitrogen is not recovered in crops grown with nitrate of soda as in those grown with other nitrogenous fertilizers, even those as slow of action as rape-cake and barnyard manure. This point is difficult to determine, since dung decomposes very slowly, and its influence is felt for many years. Thus, in the year 1875, Lawes and Gilbert could still perceive some slight effect due to dressings of dung which had been applied to pasture grass in 1863; that is to say, it had been applied to the pasture for the last time in 1863.

They found that root crops — thanks, apparently, to their long term of growth, and to the fact that they grow during the latter part of summer when nitrification is active and leaching rains infrequent — returned to them a larger proportion of the nitrogen applied in the fertilizers than cereal crops did. In one set of experiments, for example, they grew sugar beets five years in succession, and manured one parcel of them during the first three years heavily with nitrate of soda, in addition to other things; and on calculating the amount of nitrogen taken up by these five crops of beets grown with nitrate of soda, first deducting the produce grown on contiguous plots manured with ash ingredients alone, it appeared that the quantity of nitrogen obtained was very nearly equal to the amount that had been supplied in the form of nitrate of soda.

Some Crops use Soil Nitrogen freely.

Yet again, it has been shown repeatedly that the amount of nitrogen taken off by crops from land which has received no manure whatever is often large, and it is noteworthy that the amount taken differs considerably according to the kind of crop.

Thus, it was found by Lawes and Gilbert that wheat grown upon one piece of unmanured land for 32 years in succession took

off, on the average, 21 lb. of nitrogen per year and per acre, — more than 600 lb. in all, it will be noticed. Upon an adjacent plot that was dressed with a mixture of mineral manures, the wheat crop took off 22 lb. of nitrogen per year and acre.

A barley crop took off 18⅓ lb. and 22½ lb. of nitrogen per year during 24 years when unmanured and when manured with ash ingredients.

A series of root crops took off 27 lb. of nitrogen per year during 31 years, from a plot manured with ash ingredients.

Beans took off 31⅓ lb. of nitrogen per year from unmanured land during 24 years, and 45½ lb. from land dressed with mineral fertilizers.

Red clover took off 30½ lb. and 40 lb. from unmanured land, and from that dressed with mineral fertilizers, during 22 years.

Gradual Exhaustion of Soil Nitrogen.

It was noticed furthermore, that, during these long terms of cultivation, rather more nitrogen was taken off in the crops during the earlier years than was taken toward the close of the term. Thus, while the unmanured wheat crop took off 21 lb. of nitrogen per year on the average of 31 years, it took off 25¼ lb. on the average of the first eight years, and 23 lb. on the average of the first twelve years.

It would seem, therefore, that the nitrogen in the soil, derived from previous accumulations, is gradually used up by continued cropping; and in fact, careful analyses, made at different periods, of the soil of the fields where these experiments were conducted, showed conclusively that there was an appreciable reduction of the amount of nitrogen in the soil as the years went on. After 40 years' persistent cropping of the good land with wheat, it appeared that the original stock of organic nitrogen (as well as the stock of potash and phosphoric acid) had been considerably reduced, although there was still enough of all these constituents left to indicate that wheat could still be grown on that land for a very long period.

Running out of Land.

Here is seen the secret of the so-called "running out" of land. Unless land contains in the beginning an abundant store of fertility, and particularly a great reservoir of humus, the nitrogen will rapidly waste away under injudicious treatment, and the land thereby fall into bad condition. Every year a certain proportion of the nitrogen in the organic matters in the soil is nitrified by the action of the microscopic ferment, and while a part of the nitrates thus formed

is consumed by the growing crops, another part is washed out of the land in the drain-water, especially in wet seasons, and still another part is reduced and destroyed by useless fermentations.

Since, in attempting to grow root crops without any manure, the produce falls off to next to nothing after a few years, the figures cited above refer to the plot that was dressed with a complex mineral fertilizer, and in this case much more nitrogen was taken off during the earlier than in the later years.

During the first 8 years of turnips, the average yield of nitrogen was 42 lb. each year. During the next 3 years the land carried barley, which yielded 24⅓ lb. of nitrogen per year. During the next 15 years, 13 of which were with Swedish turnips, and 2 without any crop, there was a yield of 18½ lb. of nitrogen per year, and during the last 5 years sugar beets yielded 13 lb. of nitrogen per year. Here there was a reduction to less than one third during the later years, as compared with the earlier. Lawes and Gilbert found, furthermore, that the root crops exhaust the upper layers of the soil of their available supplies of nitrogen more completely than any other kind of crops.

Clover and beans, on the other hand, and in general the leguminous crops, do not thus exhaust the surface soil of nitrogen, but seem to get their supplies from below; and through the decay of the clover roots, the surface soil is left by a clover crop richer in nitrogen than it was before.

Large Amounts of Nitrogen in Good Soils.

Attention has often been called to the very large amounts of reserve nitrogen that occur in cultivated soils. Krocker showed long ago that they rarely contain less than 0.1% of nitrogen (say 3,500 lb. to the acre, taking the loam as one foot deep), and they often contain much more. A. Müller found on the average 0.26% of nitrogen in the surface soils of regions poor in lime, and 0.15% in their subsoils. In the surface soils of limestone regions he found on the average 0.66% of nitrogen. In several instances he found from 0.9 to 0.96%. Müller's averages for the surface soils are equivalent to 3.7% and 4.6% of the organic matter in the soils. Boussingault also, on analyzing a number of loams of good quality from widely different localities, found from 6,000 lb. to more than 30,000 lb. of nitrogen to the acre, taken to the depth of 17 inches, which was in the more or less inert condition above described. All this nitrogen is naturally to be thought of as additional to the comparatively small

amounts of nitrates and ammonium compounds which are usually found in loams.

Enormous Importance of the Soil Nitrogen.

Under fit conditions as to tillage and crops, and with suitable additions to the soil of phosphates or potash compounds (or both) to promote the growth of the microdemes which cause fermentation, these great stores of soil nitrogen, which are so abundant that they might almost be regarded as inexhaustible, become gradually available for feeding crops. There is hardly a more important problem in agriculture to-day than the perfecting of methods for using these great natural supplies of nitrogen to the best possible advantage. Indeed, it has already often been found more economical and advantageous to improve the quality of the soil nitrogen by tillage combined with fallows, than to buy fertilizers, or than to keep cattle for the sake of producing more manure.

Peat as a Source of Nitrogen.

It is not in arable loams alone, and in leaf-mould, that the inert nitrogen compounds are found. Here in New England great quantities of them are to be had at small cost in the form of peat, swamp mud, or marsh mud, as well as in the form of old sods taken from headlands and from beside walls; and upon many excellent farms it was customary formerly to put such materials to use. Indeed, peat deserves to be treated of as a nitrogenized manure as much as several of the substances which have been mentioned in the preceding pages.

As here used, the term peat applies to any bog earth of vegetable origin; it includes bog-meadow mud and marsh mud, as well as the more perfect peats, about the naming of which there could be no question. The New England term "muck," of course, falls within the above definition. In the Queen's English, the word muck simply means manure, i. e. well-rotted dung. It has no special reference to any kind of peat or bog mud. The New England application of the word to bog earth is a mere provincialism, natural enough in a land of hungry gravels where custom requires the farmer to try to cultivate 4 or 5 times as much land as he can manure from his barnyard.

It happens, too, as Professor Johnson has urged, that in New England the number of small, shallow depressions, containing unripe or impure peat, is much greater than that of large, deep bogs. Our farmers are in fact more accustomed to the class of deposits

which they call "mucky," than to those that would be called peat by everybody without question. It may be said that peat, no matter of what grade, almost always contains a considerable quantity of nitrogen.

A moment's consideration as to the mode of formation of peat teaches that this must be so, for all kinds of peat have resulted from the partial decay of vegetable matters. Peat is formed in boggy places where water stands at rest. In this water, successive crops of various aquatic mosses grow, often with great rapidity, and they die where they have grown, in such wise that great accumulations of partially decomposed vegetable matter result.

It is easy to see that peats and peaty soils formed in this way will be likely to contain appreciable quantities of nitrogen, while they will commonly be poor in inorganic matters, unless, indeed, sand or clay or silt happens to have been washed in upon them during or subsequent to their formation.

In 30 samples of peat, of all sorts and kinds, analyzed at the Yale laboratory under Professor Johnson's direction, the proportion of nitrogen varied from 0.4 to 2.9%. The average amount of nitrogen was 1.5% of the air-dried peat; or more than three times as much as is contained in ordinary barnyard manure.

In several of the peats the amount of nitrogen was as high as 2.4%; the low average percentage just given was due to the fact that many of the samples analyzed were of manifestly poor quality. Fully one half of the specimens were largely mixed with soil, and contained from 15 to 60% of mineral matters. One was a sample of mud from a salt marsh, and it contained 1.4% of nitrogen.

It is a matter of experience, however, that many kinds of peat contain but little nitrogen. Hence, perhaps, the farmer would sometimes do well to have a chemist estimate once for all the nitrogen in the peat at his disposal, especially in case he has several beds of it to choose between. Generally speaking, by far the larger part of the nitrogen in peat exists in a form that is insoluble in water, and comparatively inert, considered as a source of plant-food. In spite, however, of this inertness, it is a matter of familiar observation and experience, that the peat nitrogen may be made to contribute to the support of crops, and that it has consequently a considerable money value.

It would appear that when peat is exposed to the action of the

air, as when mixed with any ordinary cultivated soil, its nitrogen slowly undergoes change, and that some of it is gradually made available for the plant, much in the same way that the nitrogen of rags or of bone-meal would be under similar conditions.

It is easy, in any event, to hasten this process of conversion into plant-food by composting the peat with dung, or fish, or flesh, or alkali, as will be explained under the head of Composts.

Some Peats readily evolve Ammonia.

For some kinds of peat, at least, it is true that ammonia may be formed from their nitrogen compounds continually, when the peat is kept in a warm place and exposed to air and moisture, as I have myself seen in a series of experiments that were made in 1877, when I found myself quite unable to prepare a small quantity of peat absolutely free from ammonia. In some cases this formation of ammonia from the inert nitrogen in the peat probably depends on the action of microdemes, as in the experiments of Selmi and other observers. Compare what has been said under the head of Nitrates. But in my own experiments the conditions were such as regards temperature that living things were supposed to be excluded, and the formation of ammonia seemed to be due to processes of simple oxidation, or perhaps to the mere splitting or "dédoublement" of the inert nitrogen compounds.[1]

Valuation of the Nitrogen in Peat.

If the value of the pound of nitrogen in peat be estimated no higher than five cents, that would make the ton of air-dried peat which contains 2.5% of nitrogen worth $2.50, for this ingredient alone, to say nothing of the other useful qualities of peat which depend upon the humus contained in it, as will be explained in another place. For the present, the discussion relates only to peat in its character of a nitrogenized fertilizer, and it is to be remembered that the most valuable manures, from the money point of view, are those which contain the most nitrogen. The nitrogenized manures, such as guano, nitrate of soda, ammonia salts, blood, and flesh, cost more money per ton than any others, for the simple reason that concentrated nitrogen compounds capable of supplying this element to plants are neither abundant nor readily prepared.

New sources of phosphate of lime have continually been discovered, so that the price of this article has not risen from year to year, in spite of the greatly extended use of it. But the assimilable nitro-

[1] See note on the next page.

gen compounds are more costly than either phosphates or potash salts, and there is no immediate probability that their price will be much reduced. Hence the importance of recognizing clearly the value of the peat and the humus which are found already in the fields.

NOTE. — The peat in question was from the Bussey Farm, and was a sample left over from that used in the field experiments reported in the Bulletin of the Bussey Institution, Vol. I. pp. 87, 135. It was an immature "mucky" peat, such as is common in the bog meadows of New England, and the portion operated upon had been kept for several years in a barrel in a dry storeroom. From this material I sought to prepare a quantity of peat absolutely free from ammonia for use in experiments upon nitrification. To this end three or four pounds of the peat were thoroughly boiled with rain-water in a copper kettle, and then allowed to drain upon a percolator. This operation was repeated three times, but considerable quantities of ammonia were detected in the wash water in every instance, and there seemed to be as much ammonia in the third liquor as in the first. A small quantity of that portion of the peat which it was fair to suppose had been most thoroughly washed, viz. the fine suspended particles which only slowly settled out from the liquid, was then put in a flask together with a quantity of water that contained no ammonia, and was there boiled, pure water being added from time to time to replace that which evaporated. The vapor from the flask was cooled in a condenser, due precautions having been taken to prevent any of the peat from being carried over in the steam, and each 50 c.c. of the distillate was subjected to Nessler's test for ammonia. 500 c.c. of distillate were thus collected, and there was found as much ammonia (0.0001 grm.) in the last 50 c.c. portion as in the first. Some magnesia was then put into the flask, the mixture was again boiled, and 500 c.c. more of distillate were collected by instalments, as before. The first portions of this new distillate contained more ammonia than before (about 0.005 grm.); but after four or five of the 50 c.c. portions had passed off, the amount of ammonia became constant, and equal to what had been found when no magnesia was present. Some potassium permanganate that was free from ammonia was next put into the flask and boiled, and the amount of ammonia given off was increased; it was in fact rather more than doubled. By adding caustic soda that was free from ammonia, the evolution of ammonia was increased still more, and this increase was found to occur in the case of three separate additions of potassium permanganate and caustic soda. But after each and all of these additions, the evolution of ammonia soon settled down to the constant quantity (0.0001 grm. in 50 c.c. of distillate) that was obtained on boiling the peat with pure water.

CHAPTER XV.

CARBONIC ACID AS A MANURE.

THE importance of carbonic acid for the plant has been stated in some part in an earlier chapter. It will be well, however, to consider this substance further as if it were a manure, and to inquire more particularly as to the modes of its action and as to the possibility or advisability of increasing or controlling the natural supplies of it.

As has been shown already, there is a never-failing supply of carbonic acid in the atmosphere, into which the gas is constantly thrown by processes of combustion, decay, and fermentation, by the respiration of animals, and, in many localities, from mineral springs, volcanoes, and fissures in the earth. The gas is found in abundance in the pores of the soil, also, and dissolved in the waters of rivers and ponds.

Atmospheric Supply of Carbonic Acid.

As has been shown already, it is from the air that plants derive their carbonic acid; and although the proportion of carbonic acid in the air is only about 1 part by weight in 1,600 parts of air, — or, in terms of volumes, 1 part in 2,500 parts of air, — there is still enough of the gas to amount to three or four trillions of tons in the whole, or about 28 tons of carbonic acid for every acre of the earth's surface.

Hence, in spite of the enormous quantities which must be incessantly consumed by vegetation, as is indicated by the merest glance at such free-growing plants as tobacco, fodder-corn, sunflowers, or the eucalyptus tree, for example, there is really no difficulty in conceiving that crops are abundantly supplied with this form of food. According to Boussingault, who carefully examined a whole course of field crops, consisting of potatoes, wheat, clover, oats, and mangolds, some 1,600 or 1,700 pounds of carbon are produced in a year on the average by the crops taken from an acre of well-dunged land.

In like manner Chevandier has calculated that an acre of thrifty beech trees may assimilate in a year 1,900 or 2,000 pounds of car-

bon, or say 3½ tons of carbonic acid. Yet so large is the amount of carbonic acid in the air, that if the whole earth were covered with a forest of the kind specified, it would take eight years for this forest to consume an amount of carbonic acid equal to that now actually contained in the air.

It has been shown by numerous analyses made in different places, and at different times in one and the same place, that the proportion of carbonic acid in the air is remarkably constant. That is to say, the variations to which the amount of the gas is subject are commonly small. Of course the amount of carbonic acid may sometimes be increased unduly in comparatively small volumes of air, as when a forest burns, or a volcano is in action, or a lime-kiln, or where a crowd of men or animals are congregated; but thanks to the stirring action of the winds, these local variations are quickly lost in the great ocean of air.

The ventilating power of the wind is something enormous. Air moving no faster than two miles an hour, which is almost imperceptible, if allowed to pass freely through a space 20 feet wide, will change the air of the place 528 times in an hour.[1] Hence, having regard to their respective requirements, carbonic acid is, to all intents and purposes, supplied as freely to plants by the air as oxygen is supplied to animals. It is well that this is the case, for, practically speaking, it would not be an easy matter to control the proportion of carbonic acid in the air. In the culture of field crops, at least, we could hardly hope to be able to alter the relative proportions of the ingredients of the air, as we can and do alter those of the soil.

It does not appear, for that matter, that there would be much use in increasing the supply of carbonic acid in the air under the conditions of temperature and sunlight which now prevail. The experiments of Hellriegel have shown that an artificial supply of carbonic acid, added either as gas in the air or as a solution in the soil, had no effect to increase the yield of a crop of barley, or other grain, that was amply supplied with all other kinds of food. Hellriegel urges that the atmospheric supply of carbonic acid is probably sufficient for the production of a maximum crop under all circumstances.

[1] For a detailed statement of the amounts of carbonic acid which may be brought to an acre of land by winds of varying degrees of force, see "How Crops Feed," page 220.

This conclusion, it should be observed, does not conflict with the results of experiments in which carbonic acid water has been found to be advantageous for plants growing in poor soils, since in this case the useful effect is to be attributed to the solvent action of carbonic acid on the constituents of the soil. Hellriegel's conclusion has been arrived at by Knop also, and other experimenters operating by the method of water culture and upon other kinds of plants.

So, too, in the 40-odd years' series of experiments on field crops of wheat by Lawes and Gilbert, no beneficial effect resulted from the use, as manure, of organic matter yielding by its decomposition carbonic acid (or other compound of carbon) within the soil; whence the conclusion again, that the wheat plant, when properly supplied with other forms of food, is practically independent of any supply of carbon added in the manure. It is able to obtain and assimilate from the atmosphere all the carbon it needs, if only the necessary amounts of nitrogen and of mineral ingredients be present in the soil in available form.

Lawes and Gilbert state that barley and the various grasses are equally independent with wheat of any need that carbon should be supplied by means of decomposing manure. But they urge — what appears to have been overlooked by Hellriegel and Knop — that root crops seemed to be greatly improved by a supply of carbon from organic matter decomposing in the soil. Corenwinder also found that sugar beets grew much larger, during the later period of their growth, in rich mould from rotted horse dung, than in sand free from organic matter that was fertilized with solutions of chemicals.

It is not impossible that the root crops may profit from some other compound of carbon than carbonic acid, obtained from organic matters. But it would seem to be more probable that the carbonaceous manure in these cases may either have acted as a mulch to increase the supply of water for the root crops, or that it favored the growth of the nitric ferment and so increased the fertility of the land.

Carbonic Acid given off from the Roots of Plants.

Knop has even observed that plants upon which he experimented by way of water culture, notably maize, give off very considerable quantities of carbonic acid from their roots; and similar observations were made many years earlier by De Saussure, by Wiegmann and Polstorff, and by Boussingault. This evolution of carbonic acid by roots is manifestly a simple consequence of the natural "respiration" of the plant. Cauvet has noticed that bean plants evolve

much more carbonic acid from their roots by day, and especially before noon, when the plant is most active, than during the night, when the plant is at rest, comparatively speaking.

Plants can decompose more Carbonic Acid than the Air supplies.

Although it has been satisfactorily proved that well-fed grain crops derive no benefit when supplied throughout their entire term of growth with more carbonic acid than they would naturally find in the air, it is still true that plants can decompose a considerably larger proportion of carbonic acid than is usually contained in the atmosphere.

Godlewski has shown that, when the amount of carbonic acid in air is somewhat increased, plants decompose it readily up to a certain point of best action. But when a still larger proportion of carbonic acid is presented to them, it is hurtful, and their power of decomposing the gas is diminished. In the case of the grass Glyceria spectabilis, he found the best action on clear days, when the proportion of carbonic acid in the air was between 8 and 10%; while for Typha latifolia the best action occurred when the proportion of carbonic acid was between 5 and 7%, and for an oleander the best proportion seemed to be still lower. He found in general that starch formed in the chlorophyl grains four times more rapidly in air that contained 6 or 8% of carbonic acid, than in air which had only the normal amount of this gas. But when more than 8% of carbonic acid was present, the formation of starch was slower. The advantage derived from an increase in the proportion of carbonic acid was the more marked in proportion as the light was stronger to which the plant was exposed.

So too Schützenberger, by experimenting with the water-pest, Elodea canadensis, in ordinary water and in water that had been mixed with carbonic-acid water, so that from 2½ to 40% of carbonic acid should be present, found that up to a certain point the plant developed oxygen more freely accordingly as more carbonic acid was present, but that too large a proportion of the carbonic acid was injurious.

Godlewski found that the decomposition of the carbonic acid was favored much more by an increase in the proportion of it below the point of best action, than it was hindered by a similar increase above this point. So, too, in proportion as the light was more intense, the decomposition of carbonic acid was the more favored by an increase of the carbonic acid up to the point of maximum action,

and less hindered by such increase beyond this point. The more carbonic acid the air contained, so much the more was the decomposition of it promoted by an increase in the intensity of the light.

Above the point of best action, the decomposition of carbonic acid by leaves diminishes more and more as the proportion of it in the air is increased, until in pure carbonic acid the decomposition becomes so feeble that it might almost be said to cease entirely. Some slight action does go on, however, and it tends to increase when the experiment is persisted in for some little time; for the oxygen which results from the slight action that does occur is of course thrown into the atmosphere of carbonic acid which surrounds the leaves, and so gradually weakens it.

The hindrance to the action of the chlorophyl grains thus caused by pure carbonic acid, or by any undue amount of it in the air, is thought to depend upon the presence of too dense a coating of it, caused by the excessive pressure which it exerts upon the leaves; for it is found, when this pressure is removed from the leaves, that they can decompose carbonic acid readily enough, even when it is pure and not admixed with any other gas.

Decomposition sets in at once when the atmosphere of pure carbonic acid is somewhat rarefied by means of an air-pump. So too, when pure carbonic acid is diluted by being mixed with an inert gas, such as hydrogen, oxygen, or nitrogen, the decomposition of it by leaves will go forward. Conversely, if carbonic acid is mixed with an inert gas and the mixture is subjected to pressure, the power of leaves to decompose it will be diminished. Boehm found that, while carbonic acid was freely decomposed by leaves in a mixture of equal volumes of carbonic acid and hydrogen kept at the ordinary pressure of the air, the decomposition was reduced to a minimum when the mixture of gases was subjected to a pressure of rather more than 1½ atmospheres.

Plants suffer from an Excess of Carbonic Acid.

Practically most plants cannot long support large quantities of carbonic acid. Boehm concluded from his experiments that more than 2% of carbonic acid is hurtful to plants, and that 20% of it kills them. Davy in his day taught that, while many plants will continue to grow for some time in air that contains from one half to one third its bulk of carbonic acid, they are not so healthy as when supplied with smaller quantities of the gas. He found that some few plants withstood fairly well the action of air that was highly

charged with carbonic acid, and that one, Arenaria tenuifolia, was capable of producing oxygen in carbonic acid that was almost pure.

Daubeny, who experimented in 1848, both on flowering plants and ferns, found that the plants remained, to all appearance, unaffected for a fortnight when exposed to air that contained from 5 to 10% of carbonic acid. A few of the ferns began to suffer somewhat at the end of a month, but a Pelargonium bore perfectly well during 27 days an atmosphere that contained 10% of carbonic acid. When exposed at once to air that contained 20% of carbonic acid, many plants were evidently injured even in 2 or 3 days, or certainly in 8 or 10 days. Even when added gradually, 20% of carbonic acid was decidedly injurious. Thus, on keeping ferns in air to which 1% of carbonic acid was added daily until the proportion of it had reached 20%, and maintaining the air in this state for another term of 20 days, it appeared that most of the plants suffered severely, and that so large a proportion of carbonic acid must finally have proved fatal to them.

Twenty per cent of hydrogen, on the contrary, appeared not to exert any sensible influence upon the health of the plants, in the course of ten days. Daubeny found in these experiments that the evolution of oxygen from the plants did not keep pace with the increased supply of carbonic acid, and he inferred that, when the carbonic acid in the air exceeds a certain amount, the power of leaves to decompose it is in a great degree suspended.

Several species of ferns kept by Daubeny in air charged with 5% of carbonic acid were no more vigorous after 11 weeks' time than similar ferns kept in ordinary air. But on watering ferns with water that was moderately charged with carbonic acid, their growth was perceptibly improved.

De Saussure long ago found that young pea plants could support at intervals for some days an atmosphere of one half carbonic acid; but when the proportion of the latter was increased to two thirds or more, the plants soon withered. In air that contained 8% of carbonic acid the young pea plants seemed to thrive better than in ordinary air, so long as they were exposed to sunlight; but in the shade this amount of carbonic acid was hurtful to the plants. De Saussure's method of operating in these experiments, where carbonic acid seemed to favor growth, was to expose the plants during five or six hours daily, or as long as sunlight was to be had, to the air charged with carbonic acid, and to supply the plant with ordinary air during

the remainder of the day. These results manifestly consist with those of Godlewski, above cited, both as regards the influence of strong light and the increased decomposition when more carbonic acid than usual is present in the air. De Saussure's trials lasted during ten days or so, and he operated upon young plants. It seems not at all improbable that, if it were economically possible to provide an extra supply of carbonic acid during the hours of sunlight to plants at a certain stage of development, it might be advantageous to do so as a means of securing to the crop a good start in life, or perhaps even a more rapid development of the crop during the earlier stages of its growth, although, as Hellriegel has shown, there may not be the least use in keeping up the excess of carbonic acid after the plants have once been well grown in youth.

Pfeffer has urged as a general proposition, that leaves which are well lighted and exposed to ordinary air must evidently decompose less carbonic acid than they are capable of decomposing, because, as things are now, this gas cannot be brought to them rapidly enough by diffusion; whereas, if the proportion of carbonic acid were to be increased within favorable limits, as in the experiments of De Saussure and Godlewski, the leaves might be made to work to the utmost limit of their capacity.

This question as to the significance of a larger proportion of carbonic acid than now exists in the air, is one of great general interest, since it is a not unreasonable assumption that in earlier geological periods the presence of an excess of carbonic acid in the atmosphere may have had a very important influence upon the rate of vegetable growth. If the earth did once cool down from the molten condition, it is to the last degree probable that there was much more carbonic acid in its atmosphere at the time when plants began to grow upon the cooled crust, or in the waters upon it, than there is in the air now; for there is at the present time a vast amount of carbon stored up as coal, peat, and humus, and in limestones and other rocks, which in all human probability then existed in the form of carbonic acid gas. It is probable that the plants of those days were adapted to the circumstances which surrounded them, that they did actually decompose carbonic acid more rapidly than most of their successors, and that they were able to dispose of and stow away, as it were, the carbonaceous compounds which resulted from such decomposition.

Carbonic-acid Water a Carrier of Plant-food.

Though the furnishing of carbonic acid to the soil may be of no direct use as a source of carbon to the crop, the acid is supposed to be of immense importance in all ordinary soils, and especially for wild plants, as a means of dissolving various kinds of plant-food, or rather as a means of enabling water to dissolve them.

Water that contains carbonic acid, even when the proportion of the latter is very small, is a far more powerful solvent for many inorganic materials than mere water is. Hence it happens, that, through the formation of carbonic acid in the soil from the decomposition of organic matter, or by the bringing of it thither by rain or by absorption from the air, many kinds of plant-food are dissolved and made available which would otherwise be worthless.

Pavesi has examined pebbles of a granitic rock taken at a depth of 26 feet from a moraine near Como which had been long exposed to the action of soil-water that was more or less charged with carbonic acid. He found :

	In the corroded Rind of the Pebbles.	In the Natural Stone at the Centre of the Pebbles.
Matters soluble in chlorhydric acid	96.54	25.60
Carbonic acid	...	2.43
Oxide of iron	3.45	1.99
Alumina	...	66.91
Lime	...	3.21
	99.79	100.14

It would appear that in this case silicates of alumina and lime had been gradually changed from the insoluble condition to a state of comparatively easy solubility.

R. Müller digested the fine powder of many different minerals — feldspar of different kinds, hornblende, magnetic iron, apatite of several varieties, olivine, and serpentine — for two months at a time in carbonic-acid water, with the result that all of the minerals were more or less decomposed. The quantities of matter dissolved by the carbonic acid ranged from 0.307% (magnetic iron) to 2.111% (olivine and apatite), and consisted, in one case or another, of lime, phosphoric acid, oxide of iron, potash, silica, magnesia, and even alumina.

Similar results were obtained by Beyer (Hoffmann's Jahresbericht, 1870–72, I. 24), who caused carbonic acid to act for long periods upon powdered feldspar admixed with water and with various saline solutions.

Almost all natural waters contain more or less carbonic acid; even rain-water brings down a little of it (less than one per cent), which is absorbed from the air through which the rain has passed; and the waters of ponds and rivers receive still more of it through the decomposition of organic matters either beneath their surfaces or in the soil. Hence one chief cause of the amount of saline matter held dissolved by such waters.

In some soils the ground-water contains a great deal of carbonic acid, notably in limestone regions, as may be seen in the caves and cellars into which the water drips. For the water in coming into contact with air gives up carbonic acid, and so deposits in the form of stalactites the carbonate of lime which it previously held dissolved.

But, on the other hand, it has been observed that the water in some kinds of soils contains next to no carbonic acid. A Dutch chemist, Van den Broeck, has noticed that wells sunk a few feet in the soil of gardens, near Utrecht, contain water so devoid of carbonic acid that they give no precipitate when tested with lime-water, though the deeper wells of the same region, which reach into the sandy subsoil, contain large quantities of carbonate of lime dissolved in carbonic acid.

On further examination, it was found that the garden soil contained an abundance of carbonic acid (in its interstices) that could be removed by a current of air. Yet a column of the earth 20 inches deep by 3 inches wide gave up no carbonic acid to pure distilled water which was made to percolate through it. More than this, a quantity of water that had been artificially charged with its own volume of carbonic acid gave up this carbonic acid when put in contact with the soil.

The explanation of all this is doubtless to be sought for in a peculiar porosity of the garden soil, which permits air freely to enter it and pass through it. It is a well-known fact in natural philosophy, that when water charged with carbonic acid (or with any other gas, for that matter) comes into contact with solids which have been exposed to the air, the carbonic acid will escape from the water and assume the gaseous form. The appearance of air-bubbles on the sides of glasses in which drinking-water has been left standing, is a familiar example of this phenomenon. And the same thing may be shown still better by putting a bit of bread or dry peat into stale beer or flat soda water. In general, the rougher and

more porous the solid is, so much the more rapid will be the evolution of the gas.

It appears that the carbonic acid originally held dissolved in the water, or the beer, diffuses out into the air in or upon the solid; and that it diffuses with extreme rapidity when brought into contact with a considerable quantity of air in a small bulk, like that entangled in the interstices of a porous solid, or that which clings to the surface of any rough body. It is much the same thing as when a current of air is made to bubble through a solution of carbonic acid, or of any other gas, whereby the carbonic acid, or what not, is rapidly carried away. Angus Smith found that "nitrogen and hydrogen, when absorbed by charcoal, diffuse into the atmosphere of another gas with such force as to depress a column of mercury three quarters of an inch."

It appears from Van den Broeck's observations, that there are some soils of peculiar porosity, which favor the escape of carbonic acid from the ground-water; and it may perhaps be generally true that the tendency of most soils is to set free carbonic acid from the water which moistens them. Moreover, when moving water strikes against, or falls upon, rocks or gravel, some carbonic acid doubtless escapes from it. But, in spite of all this, the fact remains that most ground-waters contain more or less carbonic acid, and that they act chemically in accordance with this composition. It is not to be supposed that, at depths where the soil is permanently wet, that is to say, where there is no air adhering to the particles of earth or entangled by them, there can be any rapid escape of carbonic acid by diffusion, in the manner just now described.

Another point to be remembered is, that, even when the carbonic acid escapes from the ground-water, it does not necessarily escape out of the soil. For earth has the power to absorb carbonic acid, and other gases, in very considerable quantity, and to condense them within its pores, particularly when the earth is dry; and if there be anything in the earth for which carbonic acid has an affinity, it will be likely to unite therewith in spite of its adhesion to the soil. Indeed, it is not impossible that this very adhesion may increase the chemical action, and accelerate the union of carbonic acid with the inorganic ingredients of the soil.

Carbonic Acid in Ground Air.

It is a fact that the air in the interstices of most soils contains very much more carbonic acid than ordinary atmospheric air. Bous-

singault and Lewy, who studied this point long ago, found the soil air to be from 10 to 400 times richer in carbonic acid than atmospheric air, as has been set forth in tabular statements on pages 139 and 219 of Johnson's "How Crops Feed."

In air from sandy soils that contained but little decomposing organic matter, the proportion of carbonic acid was found to be only about 10 times greater than that in an equal bulk of the atmosphere. The proportion of carbonic acid in the air from loamy and clayey soils was still comparatively small (some 30 or 40 times as much as in atmospheric air), while in the air from the soil of manured fields, and from compost heaps, the quantity of carbonic acid was very large. It appears clearly from these researches, that very large quantities of carbonic acid are formed within the soil from the decomposition of manures, and of the roots and stubble of previous crops. By the application of peat also, or of composts in which peat is a principal ingredient, large quantities of carbonic acid are furnished to the soil.

Disintegration by Carbonic Acid.

It is obvious that the carbonic acid thus supplied to soils must play a very important part in disintegrating and dissolving the components of the soil. Some experiments of the German chemists Stoeckhardt and Peters bear upon this point. They filled several tall glass jars (2½ feet high by 5½ inches wide) with a rather poor loamy soil, containing considerable humus, and they planted in each jar an equal number of seeds of peas and oats. Jar No. 1 was left to itself; that is to say, it was merely watered. Through the earth of jar No. 2 about 3½ pints of air were blown daily through a tube that reached to the bottom of the jar.

Through the earth of a third jar the same bulk of a mixture of air and ¼ carbonic acid was forced, while through the earth of a fourth jar there was forced daily a mixture of ¼ carbonic acid, ¼ oxygen, and ½ air. After three months and a half the crops were harvested, dried thoroughly, and weighed. Their weights are given in grams in the following table:—

	I.	II.	III.	IV.
Oats	3.90	7.65	8.49	5.11
Peas	1.72	2.46	3.26	3.49
Roots of both	0.27	0.38	0.60	0.37
Total dry matter	5.89	10.49	12.35	8.97
Ash ingredients	0.52	0.95	1.12	1.01
If crop No. I. equals 1, then	1.0	1.8	2.1	1.5

On examining the several soils after harvest, it was found that a considerably larger proportion of mineral and organic matters had become soluble in water in jars Nos. 2, 3, and 4 than in jar No. 1. From 6,000 grm. of soil, the amounts of matter dissolved by water were as follows:—

	I.	II.	III.	IV.
Mineral matters, grams	2.04	3.71	4.99	3.91
Organic " "	2.76	4.32	2.43	3.14

Carbonic Acid occluded by Soils.

Beside the carbonic acid in ground air, properly so called, very considerable quantities of this substance are occluded in the actual earth; i. e. some carbonic acid and other gases are held so strongly in the soil that they cannot escape therefrom, either at the ordinary temperature of the air or even at the temperature of boiling water. By heating various soils to 284° F., Reichardt and his pupils have obtained results such as the following:—

From 100 Grams of	Gas given off, in c.c.	The Gas contained Per Cent of CO_2	CO	N	O
A damp garden loam	13.7	24.1	8.8	64.3	2.9
Air-dried garden loam	38.3	33.3	0.0	64.7	2.0
Peat	162.6	51.0	0.0	44.4	4.6
Hydrated oxide of iron (air-dried)	586.7	68.2	...	26.1	5.7
Clay	32.9	14.5	0.0	64.7	20.8
Clay after long exposure to the air	25.6	25.1	0.0	70.2	4.7
Powdered gypsum	17.3	0.0	0.0	81.0	19.0
Pine charcoal	164.2	...	...	100.0	...
Poplar	467.0	16.5	0.0	83.6	0.0
Bone	84.4	45.8	0.0	54.2	0.0

This power of the soil to occlude carbonic acid and other gases is merely a particular instance of a general law which has long been recognized as regards charcoal and has latterly been found to be true of all solid substances.[1] The power of iron oxide to occlude carbonic acid is so well marked that it has been said that the amount of this gas occluded by a soil is proportional to the amount of iron contained in it.

Modes of Action of Carbonic Acid in the Soil.

As for the mode of action of carbonic-acid water in the soil, it dissolves some carbonates directly, such as carbonate of lime and carbonate of magnesia. From silicates, it dissolves out potash, soda, lime, and magnesia, since it is a more powerful acid than silica is

[1] Compare "How Crops Feed," p. 165.

at the ordinary temperature of the soil. As was stated before, it is easy to test this action by passing carbonic acid gas through water that is made to hold in suspension almost any finely powdered mineral. Considerable quantities of potash, soda, lime, and magnesia may soon be found dissolved in the liquid. When made to act upon phosphate of lime, carbonic acid gradually removes lime, so that finally some soluble acid phosphate of lime is formed.

Little is known, as yet, as to the precise significance of the carbonic acid which is given off from the roots of growing plants, though there can be no question that the fact is one of much importance. Inasmuch as this carbonic acid can hardly fail to act upon matters in the soil to dissolve them, it would seem to follow that there may often be as much, or perhaps more, disintegrating of rocky materials in a field kept covered with vegetation than if the field were left to lie naked and fallow; not to speak, for the moment, of the action of acids other than carbonic which are exuded or excluded by the roots of plants.

Carbonic Acid a Result of Ferment Action.

Nevertheless it is not at all unlikely that the formation of carbonic acid in the soil may depend more intimately on fermentations, due to the presence of microdemes in the soil, than on the action of the roots of plants. I have myself found that very considerable quantities of carbonic acid are formed in air-dried soils, probably by the action of microdemes; and there are some reasons for believing that both droughts and bare fallows may occasionally be useful in that they promote peculiar kinds of fermentations which produce incidentally large quantities of carbonic acid, whereby disintegration may become more rapid than would otherwise have been the case. (Compare Bulletin of the Bussey Institution, 1878, II. 195.) Wollny in experiments lasting from May to October, found in air taken from the soil at a depth of 10 inches beneath grass sod 4.4 less carbonic acid on the average than was contained in air taken at the same depth from beneath bare land, and 3.4 less than was contained in air taken from land whose surface had been kept shaded by a covering of straw. In general he found less carbonic acid in the air of the soil in proportion as the surface of the soil was more thickly covered with vegetation. In some experiments, however, that were made in November, March, and April, i. e. at a colder time of year, more carbonic acid was found in the

air of the soil that was covered with grass than in the air of the bare land.

The importance of carbonic acid in the soil as a means of dissolving lime for preventing the puddling of clay will be treated of under the head of Lime.

CHAPTER XVI.

GREEN MANURING.

Many substances employed as fertilizers produce such large quantities of carbonic acid in the soil that it is but natural to ask whether some part of their utility may not be due to this peculiarity. Farmyard manure, for example, as well as composts, leaves, straw, and sea-weeds, are comprised in this category; and, especially, the method of fertilization known as green manuring.

For temperate climates, it is a commonly accepted, and doubtless a true opinion, that, if time enough be allowed, almost any land not absolutely arid or poisonous can be made fertile by persistently sowing buckwheat or clover or rape-seed or lupines upon it, and ploughing in the green crop before it comes to maturity.

This method of green manuring, as it is called, is a singularly philosophical method. As a mere matter of reasoning, or of reasonableness, it will well repay a careful examination.

In the first place the seeds of plants are sown, which, like peas or clover, have a peculiar faculty for profiting by the food they find in the air and deep in the subsoil; or plants are chosen which, like the lupine, or like buckwheat or rye, have the power of extracting nourishment from the earth even under very unfavorable conditions. These plants are allowed to grow until they have gathered from the soil all the matters they are capable of gathering; that is to say, the plants are left until they are in flower, and then they are ploughed under. By operating in this way, the land is manured with everything that the plants have accumulated, either from the air, or from the soil, or from the waters in the soil; and there is placed within the land a mass of organic matter which by its decay will give off enormous quantities of carbonic acid to disintegrate and dissolve the components of the crude soil.

Humus itself is Important.

The organic matter will, moreover, furnish an abundant supply of humus for absorbing and holding moisture, for supplying nitrogen, and for improving the texture of the land. Hence it happens that by means of this system of green manuring many a leachy, hungry soil may, with comparatively little trouble, be made capable of retaining water and manure, and so of supporting crops. By cultivating the white lupine to this end, it has been found possible in Saxony to cover mere drifting sands with useful vegetation.

Instances are not wanting in agricultural practice of fairly fertile soils which consist naturally of no more than a small proportion of humus admixed with mere sand. Boussingault noticed in South America a very fertile soil that was composed of 92% of sand admixed with leaf-mould. It is said that in Belgium many instances occur where arid sands have been made fertile by continually applying to them street sweepings and stable manure. In such cases the humus appears to act very much in the same way that clay would act to improve the physical texture of the soil, and so enable it to hold water and fertilizing matters.

Generally speaking, green manuring is practised on poor, thin soils, but it is said that not infrequently heavy clays have been greatly benefited by it, the introduction of organic matter having made the clay less adhesive and sticky than it was before, and better fitted to support the operations of tillage.

Plants used in Green Manuring.

Beside the plants already specially mentioned, there are several others which are sometimes ploughed in green, — notably rye, which, like the lupine and buckwheat, has a peculiar faculty of extracting food from poor land, turnips sown thick, white mustard, Indian corn sown thick, and peas. At the South, a kind of bean, called the cow-pea, is largely used, as vetches are abroad.

In one sense, Green Manuring is a Common Practice.

It is noteworthy, that one form of green manuring prevails generally upon the thin soils of New England where hay is the staple crop. For whenever the sod of old grass-land is ploughed under, the land gets the benefit of what is really a green manuring of considerable strength.

Throughout the Eastern States, and even in the immediate vicinity of Boston, the farmers generally keep most of their land in grass as long as the yield of hay continues to be fairly remunerative, and

they count upon the old sod as a source of nutriment for subsequent crops.

One way of proceeding is to turn the sod under with the ploughshare, and to harrow in rye without adding any manure. Here the case is one of green manuring pure and simple.

After the rye has been harvested its stubble is ploughed in, and the next year the land is planted with potatoes or corn or roots, — with addition of barnyard manure, — as a preparation for laying the land down again to grass. The old sod is found to be thoroughly rotten and friable when the rye stubble is turned in.

There are of course several other ways of dealing with the inverted sod. Some farmers plough it under in the spring, and plant potatoes upon it in the first year, or corn; others plough in August or September, and sow grass-seed at once as soon as the old sod has been turned under. The rye method has been mentioned particularly, because it seems to be specially philosophical.

So too in respect to Indian corn, there is a reason why this crop is specially well fitted to be grown on sod land. Since corn needs to be planted rather late here in New England, the sod land can be left unploughed until the grass has sprung up and has covered the land with a green crop; and when the green sod is turned under, fermentation soon sets in; the sod decays rapidly, and nitrification succeeds the first fermentation in due course, so that whatever plant-food the young grass may have collected is probably fully utilized by the corn. Mere "spring ploughing" would not have given these results, i. e. not if the ploughing had been done before the grass plants had had time to grow. Some people have occasionally gone so far as to turn sods directly upon potatoes, as a means of planting. They plough three or four furrows in the sod, drop the "seed" in the fourth furrow, perhaps, and then turn the next furrow upon the sets as a covering.

Amount of Organic Matter in Sod.

An interesting experiment as to the amount of vegetable matter afforded by an old sod was tried in Massachusetts, many years ago, by Mr. Phinney of Lexington, a noted farmer in his day. In May, 1828, he cut out a square foot of greensward from an old grass field; he separated the roots and grass from the loam and humus, and found that the weight of the vegetable matter was 9 oz., which was at the rate of over $12\frac{1}{4}$ tons to the acre. The soil of the field was thin loam upon a gravelly subsoil; the field had been laid down to

grass three years, but the crop of hay had been so light as not to be worth more than the cost of making.

The Italian chemist Sestini has determined the weights of total crop and of nitrogen yielded by beans (Phaseolus) and by lupines when grown to be ploughed under as green manure, near Rome. As reported in the German journals, he found 28 tons of the green bean plants to an acre, and 19 tons of lupines. The bean plants on an acre of land, taken when in blossom, contained 280 lb. of nitrogen, and the lupines 117 lb. In these experiments, as in the one relating to grass, it is to be presumed that the roots of the crops are included in the statements.

Green Manure may act slowly.

A point to be noticed in respect to green manuring is, that the inorganic matters and the nitrogen in the buried plants are only gradually given up, as a general rule, for the use of the next crop. Probably the living plant cannot consume many of the constituents of the dead plants until the latter have been completely disorganized. This point is one that needs to be borne in mind; it would be on the whole disadvantageous, though something might be gained by it occasionally.

In any event, it is hardly fair to compare green manuring too closely with the ordinary methods of applying fertilizers, for it is in some respects a law unto itself.

Green Manuring rarely practised.

Excepting the turning under of old grass-sod or clover-sod, or of grain crops that have been partially winter-killed, green manuring is resorted to only in exceptional cases nowadays, though it was once rather common in many localities in the days when commercial fertilizers were not to be had. In the Southern States of this country, however, it is said to be still a rather common practice to plough under the cow-pea. One good method proposed and practised by Ravenel, of Charleston, is to apply finely powdered phosphate rock ("floats") to the land on which the cow-peas are to be grown; so that, when the green plants come to be ploughed under, the refractory phosphate shall be subjected to the solvent action of a great mass of decaying vegetable matter, whereby some part of it may be made fit to be assimilated by subsequent crops.

Clover as Green Manure.

In the same way that grass-sod is made to furnish green manure in New England, so is clover-sod in several European systems of

rotation, and in the wheat-growing regions of New York and some of the less distant Western States. Indeed, there is a saying current in many districts to the effect that "clover-seed is the cheapest manure a farmer can buy."

Since clover forms a thick mat of roots, the turning under of a mere dry stubble of it gives to the soil a considerable amount of organic matter in any event. But there is a system of culture occasionally practised in several European countries, in which care is taken to convert the stubble into greensward before ploughing it under. To this end, a portion of the barnyard manure, or other fertilizer, that would be allotted in any event to the next year's crop, is applied as a top-dressing to the field immediately after the clover has been mown. The abundant crop of aftermath thus obtained is then ploughed in at the farmer's convenience.

Since the clover treated in this way brings into the soil from the air a large quantity of humus-producing materials, without wasting any of the manure that was applied to it, the method would seem to be a peculiarly happy device for applying manure economically. It may well be asked whether it would not often be best, in cases of green manuring, to encourage the growth of the green crop by dressing it moderately with manure.

Green Manure a Source of Humus.

It is to be noted, that, by operating in this way, an abundant supply of organic matter may be added to the soil through the intervention of purely inorganic manures, such as guano, or superphosphate, or wood ashes. In view of this fact, one of the objections most commonly urged against the use of the inorganic or mineral fertilizers falls at once to the ground. It has been suggested repeatedly, both by systematic writers and by practical farmers, that the long-continued use of inorganic manures must inevitably impoverish the soil, since in using them continually no supply of humus (such as is given in barnyard manure) would be brought to the soil. But manifestly it is an easy matter to raise a crop of humus once in a while for the land, and upon the land, whenever it may be needed. This might be done, if need were, in late summer, after an early crop had been harvested. There would be no necessity for giving up the use of the land for an entire season. So far from any manure being wasted when thus used to force a clover stubble, the sum total of manure is actually increased by whatever the clover has taken from the air.

Of course, in a dry grazing country like New England, where the "fall feed" for pastured cattle is no small item to be taken into consideration, the foregoing system of clover-forcing would seldom be justifiable. The green crop would be fed out, either green or dry, to cattle who would return dung to the land. Perhaps the land would not be so well manured in this way for the time being, but the advantage to the farmer would nevertheless be greater in most cases; for, in spite of the cost of harvesting the forage, of carrying it to the cattle, and of carting out and spreading their manure, it would still be true in the long run, upon a well-conducted farm, that the farmer will get two profits, — one from the animal increase or other product obtained by using the fodder, and another from the manure which the fodder has produced.

Rather than plough under the clover, it would be better on many farms to mow it once for hay, and again for seed to be sold. For with the money the seed brings in, cotton-seed meal, corn-meal, bran, or malt sprouts may be bought as a means of producing dung. It is a fact, as will be explained hereafter, that animal excrements act as manure more quickly, more powerfully, and more assuredly than the plants which have produced them can.

Generally speaking, all green crops are thus fed out nowadays, and it seldom happens that a crop is ploughed under if it be thrifty. Nevertheless it may sometimes be well to force old sod-land in the spring, in the manner just now indicated, as a preliminary to planting corn, provided the land is well suited for the purpose. So too, when Indian corn is grown after winter wheat, one way of proceeding is to sow 10 or 12 lb. of clover-seed to the acre upon the wheat in the spring, and to plough under the clover the next spring in the latter part of May, by which time a vigorous growth will have started, and immediately to plant corn upon the inverted sod. There must always be exceptional cases, as of fields far from the homestead, where green manuring may be advisable. And in cases where a crop has grown so feebly that it promises to be hardly worth the trouble of harvesting, it may sometimes be good practice to plough the crop under, out of hand. In such event, where the amount of herbage to be ploughed under is but small, there need be little or no delay in sowing seeds upon the land for another crop, especially as regards some kinds of crops; but when a heavy green crop has been turned under, time enough has to be allowed in many cases for the buried plants to decay before the seeds for the

next crop can be sown, lest they too be destroyed by the process of putrefaction. For example, it was a rule among Saxon farmers, that, when rape-seed was to be sown in autumn after clover, the latter could not be mown twice or thrice during the course of the summer. On the contrary, the stubble was ploughed under after the first cutting of the clover, and left to decay until September, when the rape-seed was sown.

Green Manure versus Fallows.

In general, it may be said that the practice of green manuring militates strongly against the system of allowing land to lie in naked fallows.

Beside the opportunity afforded for nitrification, one chief merit of fallowing is supposed to consist in the opportunity afforded for destroying weeds on land which has become insufferably foul. Long before fallows were discarded in countries the agriculture of which is somewhat advanced, it had come to be a tenet of good practice that the fallow land must be ploughed repeatedly, so as to bury the half-grown weeds as often as a new crop of them had sprung up. Thus the practice of green manuring is in some sense an outgrowth from the system of fallowing.

Fallows were at one time defended, it is true, upon the ground that all land needs rest occasionally. But, as was just said, long before the practice fell into disrepute, it had become a feeble system of green manuring, in which the weeds constituted the green crop. But manifestly, if it is proposed to practise green manuring, it will be best to practise it thoroughly. If a field is to be given over for a season to the production of green manure, economy demands that, by means of some appropriate seeding, it shall be made to produce a fair crop of the desired manure. And it is easy by means of light dressings of artificial fertilizers to grow several tons of the green crop, and so to plough in a mass of fertilizing material which in so far as mere weight goes will compare favorably with a moderate manuring with dung.

Even if the destruction of weeds is the thing specially desired, it would be best to grow a succession of green crops throughout the summer, one after another, upon the inverted sod of the previous tender plants, and it might often be well to let cattle or sheep run upon each of these short green crops a week or so before ploughing them under, in order that some of the best of the forage should be eaten off. English experience goes to show that white mustard

would be well suited to this purpose; for no more than six or eight weeks are needed for it to grow, and two or three crops of it might readily be ploughed under in a single season, and time enough still be left for seeding down the land to grass or grain in the autumn. The mustard is said to need only a light ploughing, and a peck of seed is held to be enough for an acre of land.

Rib Ploughing for Burying Weeds, etc.

There was an old English system of ploughing, called "ribbing," that deserves to be studied anew in connection with the subject of green manuring. In ribbing, the plough was made to turn up a thin slice of sod, and lay it over flat, face downward, on the adjoining surface of undisturbed sod.

At a proper distance from this first furrow, namely, at the next furrow but one to it, a second slice of sod was inverted upon the strip of undisturbed sod that had been left to be buried; and so the entire field was thrown into a system of low ridges and shallow furrows. The herbage was in this way completely buried, though only half the surface of the land had been actually ploughed, and that with light labor.

In the old English practice the sods were left thus buried face to face until the grass and roots had rotted, when the entire surface of the land was broken up by means of a heavy harrow, or by ploughing the field across.

It seems probable that this method might sometimes be applied with advantage upon land foul with weeds, in cases where a couple of crops of green manure were to be grown in a single season. The first crop of green manure might be ribbed while the plants were young, and the second crop sown upon the ribs without disturbing them. Finally, the last crop would be ploughed under crosswise.

Perhaps the method of ribbing could be used also for the improvement of old pastures, run out to white-top or other useless grasses. For with a comparatively small expenditure of labor it would be possible in many cases to destroy the old grass, and to bring the land into such shape that white clover and fine-top, and June-grass or orchard-grass would flourish upon it, when simply sown on the ribs without further tillage, perhaps even without any other manure than the rotting sod would give.

Green Crops shade the Land.

There is one merit in green manuring that has been strongly insisted upon by some writers; viz. that by shading the ground the

crop brings the soil into a favorable condition of fermentation, whereby useful chemical actions are induced and maintained, at the same time that good physical conditions are insured.

It is undoubtedly true, as regards the surface soil, that shade does act something like a mulch to keep the land open and mellow, as well as to protect it from the baking influence of the sun and the formation of crusts by beating rains. So many weeds are choked withal by the green crop, that the land may be cleaned thereby to an appreciable extent. But, as will be shown hereafter, the very crops which shade the soil best and keep its surface mellow are precisely those which pump the largest quantities of water out of the lower layers of the soil, and tend to leave it so dry that succeeding crops may be injured. Moreover, the good effects of shade are in no sense a peculiarity of the process of green manuring. They will be felt just as strongly when the crop is to be harvested and used for fodder, as when it is to be ploughed under.

Lupines, both the yellow variety and more especially the white, have been used from time immemorial for green manuring in Italy, and to a very considerable extent in Saxony also, since the middle of this century. The plant has several peculiarities which specially fit it for this purpose. It appears, indeed, to be by far the best plant for the purpose which has yet been discovered. It grows rapidly even on sandy soils, and sends its roots deep down into the earth; it stands drought well, and is said to be very little troubled by insects; it is leafy and voluminous, so that it shades the ground abundantly, and yields an enormous burden of organic matter. But since the hay and seeds obtained from it are somewhat liable to poison animals, and are bitter withal and repugnant to animals until they have become habituated to their use, there is less incentive to harvest the crop than would otherwise be the case.

Lupines grow well on sandy and loamy soils, as well as on those rich in humus or clay. But they do not succeed on cold land, nor on marls. On account of the great bulkiness of the mature crop, it is usual to mow it before ploughing. Sometimes the mown plants have to be raked into the furrows.

Effects of Green Manuring.

The following examples of results obtained by growing rye, after green manuring with lupines, are taken from Heiden. One half of a field was sown with 60 lb. of lupine seeds, and the other half was left fallow. When the lupines were well grown, the whole field

was ploughed and sown with rye. In one case there were harvested in pounds the following amounts:—

	Grain.	Straw and Chaff.
After the lupines	532	1072
After the bare fallow	322	656

In another case,—

After lupines	400	609
After bare fallow	245	503

In other cases, where the stand of lupines was light,—

	Grain.	Straw and Chaff.
After lupines	270 and 259	498 and 542
After bare fallow	216 " 191	423 " 388

In another case, rye was grown on a sandy soil after yellow lupines, on plots of 24 square rods, as follows:—

	Grain.	Straw and Chaff.
I. Where lupines were ploughed in	96	205
II. Where lupines were mown and carried to III.	64	130
III. Where lupines from II. were ploughed in	66½	136
IV. After bare fallow	56	114

Examples of Green Manuring.

Some American examples of green manuring have been reported as follows. Plough the land in June, harrow in buckwheat, and plough the buckwheat crop under in August, or before the seeds begin to ripen. Finally, sow winter grain in the autumn. It is said to be a good plan to lime the land after ploughing in the buckwheat; and, as a general rule, some 25 bushels of lime to the acre is esteemed to be a useful application after a green manuring. If the crop of green manure be large, the plants should be rolled heavily before ploughing them, so that they may be fully covered with earth, and care should be taken to bury them deeply, so that enough moisture may be retained to insure speedy decay.

Another way of proceeding is to sow white turnips after the buckwheat above mentioned has been ploughed in, and to plough under the turnips in their turn in the spring. The turnips have the merit that they will continue to grow in the autumn after the early frosts. In some seasons they will grow a good deal at that time. Still another way is to sow rye on the buckwheat sod, and to plough in the rye the next May, when it is 3 or 4 feet high, and plant corn upon the land.

In case a crop has been removed from the land so late in the season that turnips cannot be grown upon it for sale, rye may be

sown, either to be pastured in late autumn and early spring, or to be cut green in the spring, or to be ploughed under at that time, as circumstances may dictate. Rye will grow freely in warm autumn weather, especially on moist low-lying land, and will not only check the growth of weeds, but pick up the nitrates in the soil, and prevent them from being washed away by the rains of autumn and spring. In so far as this saving of nitrates is concerned, it will usually be true that the richer the land the greater will be the need of keeping it covered with growing crops during autumn, winter, and spring, in order to prevent leaching by rain. In summer, as has been shown, comparatively little water soaks out from the majority of cultivated fields.

One Trouble with Green Manuring.

It is commonly taught that green manuring is specially adapted to sandy soils in climates that are rather dry, though it has often been employed with advantage on heavy land. But there is one danger that needs to be kept in view and guarded against when possible. On light land serious trouble might ensue if a drought should set in immediately after a green crop had been ploughed under. For, unless there be moisture enough in the soil to rot the buried plants, the field would be left in a bad condition. In case of need, the land should be rolled after the ploughing, and it might even be subsequently harrowed lightly, i. e. cultivated a little at the surface, to prevent the moisture from drying out from the rolled earth.

It has even been noticed, on light sandy loams, that strawy horse manure may sometimes give lighter crops than cow manure, because of too much lightening up of the soil. That the converse of this is true is well known, horse manure being specially esteemed for cold, heavy soils.

Manifestly, green manuring is a method of fertilization that needs to be used with care. It will always be safest in the beginning to experiment with the process cautiously before subjecting one's self to expensive risks. If the condition of the soil is favorable as regards moisture and texture, green manuring might be a valuablo resource. But if the conditions are unfavorable, the ploughing in of green crops might do more harm than good, and involve the operator in wasteful expenditures.

After all has been said that can be in favor of the system, it still remains true that, excepting old sod land, green manuring is a re-

source for the landscape gardener rather than for the farmer. It may serve a good purpose in cases where waste pieces of land need to be beautified quickly and at small cost; but under the arrangements that commonly exist upon farms nowadays, it will usually be found more economical, as has been said, to harvest any green forage that may be grown, and to feed it out to animals whose dung will be returned to the land at some appropriate moment in the course of a judicious rotation of crops. For the owners of most farms, especially if their land be fertile, it is from the scientific point of view, and not from the practical or economic, that green manuring is to be regarded as interesting and philosophical.

Straw of Grain.

The value of straw as manure is evidently less than that of green crops; for there is necessarily less nitrogen in straw, and a smaller proportion of those inorganic matters which are valuable, than there is in young herbage. It is known that, as the seeds of a plant ripen, most of the phosphoric acid and nitrogen, and much of the other specially useful ingredients, pass up out of the stalk of the plant into the seeds.

According to Stoeckhardt, 2,000 lb. of absolutely dry straw contain

	Wheat.	Rye.	Barley.	Oats.
Organic matter	1920	1940	1910	1900
Nitrogen therein	8	6	6	6
Inorganic matter	80	60	90	100
Potash and soda	12	11	24	28
Lime and magnesia	6	7	10	10
Phosphoric acid	4	2⅓	4	3
Silica	56	36	46	50

Of course, these numbers are mere approximations to an average. In special cases, where the crop has been heavily manured, or the season has been moist, though not over wet, the amount of nitrogen may be twice as great as is here given. It is to be observed, also, that the figures refer to straw dried at the temperature of boiling water. Ordinary straw contains some 8 or 10 or 12% of moisture.

It is a matter of experience that the nitrogen in straw is less efficient than that in green vegetable matter. In fact, the chief value of straw, considered as a fertilizer, must be attributed to the ash ingredients which are contained in it.

Some interesting Saxon experiments bearing upon the value of straw are quoted by Stoeckhardt. A farmer manured his land for

several years with a couple of swamp plants, — one part of the land with the cat-tail and the other part with the large bulrush. He found that, while the cat-tail was a really useful manure, the bulrush had scarcely any fertilizing power for his land.

On subjecting samples of these plants to analysis, there were found in 2,000 lb. of the dry

	Cat-tail. lb.	Rush. lb.
Organic matter	1,900	1,960
Ash ingredients	100	40
	2,000	2,000
Nitrogen	12	11
Potash and Soda	22	1+
Lime and Magnesia	32	8
Phosphoric acid	5½	2
Silica	8	22

Since the proportion of nitrogen and of humus-forming ingredients is nearly the same in both plants, and the chief difference is found in the proportion of alkali compounds and phosphoric acid, it is fair to infer that neither the nitrogen nor the humus-formers are of so much value in these plants as the inorganic materials.

Straw a Salable Crop.

Reference will again be made to straw under the headings Dung, Urine, Compost, and Potash. Properly speaking, however, straw belongs among foddering materials, and is in most situations worth more as fodder than it is worth as manure. Moreover, in many localities straw is worth still more for various purposes outside the farm than it is worth as fodder and manure. Generally speaking, wherever there is a market within reach, straw had much better be sold as such, and the price of it expended, if need be, in buying some other form of manure. For purposes of packing, and for bedding men and animals in cities, straw usually commands a price which takes it out of the category of manures. It should be seldom if ever thought of as a manure nowadays in regions where it is salable.

Sea-weeds.

Several sea plants, or, as the common expression is, sea-weeds, are largely used as manure upon our own sea-coast and upon the coasts of Great Britain and France. These sea-weeds are of various kinds, but in New England the farmers usually divide them into three general classes, viz. eel-grass, rock-weed, and sea manure.

Eel-grass (Zostera marina) may first be treated of, not, however, because of its value as a fertilizer, for it is the least valuable of all the sea plants. On the contrary, it is chiefly interesting because it so well illustrates what was just now said of straw; viz. that the mere fact of a thing's being of organic origin does not in any way prove that it has much value as a manure.

Eel-grass is, in fact, a sort of flat straw; it contains some nitrogen (some 1⅓%), and a large proportion of what might be supposed to be humus-forming ingredients. More than 70% of the air-dried eel-grass is organic matter. But, taken by itself, the eel-grass has little or no fertilizing power. It will hardly rot anywhere, either in the ground, in the hog-sty, or in the manure or compost heap. It is a distinctly inconvenient thing, moreover, to have in the way of the ploughshare or the dung-fork. It has long stood as a kind of reproach among the vegetable manures, much as leather scraps stand in the list of animal products. For mulching, and for banking up in autumn around stables, greenhouses, cisterns, cellars, and pumps, eel-grass has been found useful, and this is about all that could have been said in its favor until very recently. Considered as a manure, it was rejected by the farmers long ago. It had been tried and found wanting by numerous generations of men.

Still, on analysis, it appears that eel-grass contains a considerable proportion of fertilizing matters, and there can be no doubt that it will be found amenable to proper treatment, and will eventually be prized as a manure.

Besides 1⅓% of nitrogen, air-dried eel-grass contains 1% of potash and 0.25% of phosphoric acid. The ashes of eel-grass contain 7% of potash and 1½% of phosphoric acid, which is as much as ordinary house ashes contain.

The trouble with eel-grass is, as was said before, that it will not rot in the soil. It must be coerced in some way in order to make its fertilizing constituents available for crops. It might be burned, for example, to ashes, in order to get the potash and the phosphoric acid; or, much better, the organic matter may be disorganized by composting the grass with lime. Or in some cases, perhaps, it might be found convenient to destroy the texture of the grass by moistening it with dilute sulphuric acid. For most cases, the best way will be, doubtless, to throw the eel-grass into heaps with layers of lime interpolated, and so to reduce the resisting tissue to a manageable form.

Sea Manure Proper.

The really fertilizing sea plants, i. e. those which are esteemed as fertilizers, belong to the class of Fuci, including the broad kelp or devil's-apron, ribbon-kelp, rock-weed, and carragheen, or to the class of Algæ. All these plants are highly mucilaginous, and they contain much nitrogen. They might almost be compared to flesh, without going very far wrong. When fresh, these plants contain a very large proportion of water; hence, when they once begin to decay and become disorganized, they melt down into a very small bulk, and seem almost to dissolve away.

Since the tender organic matter of these sea-plants decomposes very easily, and has, moreover, no power of absorbing liquids such as is possessed by straw and leaves, there can be nothing gained for the sea manure either by composting it or by allowing it to ferment before it is applied to the land. It may, however, be used as a sort of yeast to induce fermentation in peat, i. e. to improve the peat. Practice accords with theory in this particular, sea manure being usually either ploughed in green or spread upon the land as a top-dressing in as fresh a state as it can be procured. In either case the sea manure decays very rapidly, except in times of drought, and produces its chief effect upon the first crop. The rapid action is in this case one of unmitigated advantage, for wherever sea manure is to be had at all, it can generally be obtained one year nearly as well as another, and it may therefore be supplied to the land as often as is desirable.

It is an easy matter withal for the farmer to keep a large stock of cattle upon the grass which the sea manure nourishes, and so to supplement that kind of manure by the dung of cattle thus kept. But the stable manure, though helpful, is not essential. There is an island on the coast of France where sea-weeds and the ashes of dung are the only manures employed upon the farms. Cattle are kept, indeed, in large numbers, but the dung is all dried and used for fuel.

Here in New England there is abundant evidence of the great value of sea manure. If we throw out of consideration the intervale farms of the Connecticut River and its tributaries, which are practically farms manured by way of irrigation, and the farms that depend upon the manure derived from great cities, and perhaps some farms upon Buzzard's Bay, Long Island Sound, and the coast of Maine that are based upon fish manure of one kind or another, the only really fertile tracts in New England are to be

found back of those sea-beaches upon which an abundant supply of sea-weeds is thrown up by storms.

The strip of country behind Rye Beach, in New Hampshire, comprising the towns of Rye, Greenland, and Northampton, affords a striking example of this fact. Abundant crops of hay and (in former times more than now) of potatoes are there grown and sold year after year, while the country remains fertile and fortunate.

It is interesting to see the fields in that region remain green throughout the summer droughts, at times when the scantily manured fields of the interior are brown and parched. It is not the showers of summer alone, but the good tilth that comes with cultivation and careful tillage, as well as abundant supplies of plant-food, which enable crops to support intense heat. In the district now in question, the use of the sea manure extends back some 8 or 10 miles from the beach, and to a less extent even to 12 or 14 miles.

The enormous amount of useless water that has to be transported in the sea-weeds practically limits their use to the immediate vicinity of the beach; it explains, too, the popular impression that this kind of manure is transient in its effects, and needs to be frequently renewed. For in view of the large proportion of water in sea manure the proportion of other things that are contained in it must be small, and the land is really manured very lightly in using it, although the farmer may haul and distribute a great mass of bulky material.

It is because of its containing so much water, doubtless, that in a cold country like Sweden the peasants, as noticed by Linnæus, do not put sea manure in the fresh state upon wet soils. It would be slow to ferment and decay there.

One advantage which the sea manure shares with the commercial fertilizers is its entire freedom from the seeds of weeds, the spores of fungi, and the eggs of insects. It is a comparatively easy matter to keep a farm clean and in good heart when there is no innumerable host of weeds to overrun the land, to dissipate its moisture and sap its strength, and to distract the farmer and hinder him from tilling the land as he would like to do.

The growth of sea-weeds is often very rapid. It is recorded of a rock on the coast of Scotland which is uncovered only at the lowest tides, that it was one year chiselled smooth in November, and that on the following May, less than six months afterwards, it was thickly covered with ribbon kelp two feet long, and ordinary kelp six feet long.

Composition of Sea-weeds.

Analyses of various kinds of fuci by Marchand show that these weeds contain when fresh from 74 to 80% of water, 18 to 24% of organic matter, and 3 to 4% of ashes.

Some determinations of my own, made upon fresh eel-grass and rock-weed taken from Hingham Harbor, gave, in eel-grass: —

	Per Cent.
Water	85.03
Organic matter	12.35
Ash	2.62

In rock-weed: —

Water	77.94
Organic matter	18.12
Ash	3.94

After subtracting water, Marchand found the fuci to contain from 80 to 90% of organic matter, and from 10 to 20% of ashes; that is to say, vastly more ashes than are yielded by fire-wood. The fresh plants contain from 0.25 to 0.50% of nitrogen. He found that the ashes contain of useful ingredients, from 7 to 10% of potash, or in exceptional cases 15%, 10 to 15% of lime, 4 to 8% of magnesia, and 2 to 4% of phosphoric acid.

More recently, Griffiths reports 14.90% potash in the ash of Fucus vesiculosus, and 5% in that of F. serratus. He finds 2.38 and 3.93% phosphoric acid respectively in the two kinds of ashes, 10.47 and 14.78% of lime, and 7.30 and 10.39% of magnesia.

Bergstrand found in the ash of F. vesiculosus 7.7% of potash, 1.9% of phosphoric acid, 13¼% of lime, and 9⅓% of magnesia. He found 0.32% of nitrogen in the moist weed, and 1.46% in that which had been dried.

Sea Manure a Potassic Fertilizer.

It appears from all this, that the sea manure, though a "complete manure," as the term is, — i. e. one capable of yielding to crops nitrogen, phosphoric acid, lime, and magnesia, as well as potash, — is nevertheless specially rich in potash; and that it might be looked upon as a potassic manure, much in the same way that guano is regarded as an ammoniacal manure.

It will be shown farther on, that the potassic manures are specially favorable to the growth of clover; and it is not a little remarkable that there is perhaps hardly another locality in New England where red clover may be seen growing so freely and abundantly as upon the tract of country back of Rye Beach, just now

mentioned, which has been manured with sea-weeds ever since the country was first settled. Clover grows there naturally and spontaneously, in the sense that it perpetuates itself and remains in the land year after year, much as June-grass does in other localities.

Shrinkage of Sea-weeds.

The facts that the valuable sea-weeds contain nearly 80% of water, and that eight tenths of all that is not water is a soft, easily decomposable form of organic matter, explain the extraordinary amount of shrinkage that is often noted when heaps of sea manure are left to themselves. Very large heaps have been known to disappear almost entirely in the course of a couple of years, nothing remaining but a little black fibrous matter, which probably represented the external portion of the original heap that had been made dry and crisp by the action of the weather. It is worth remarking that a mixture of bone-meal and sea manure would make a very complete manure, perfectly competent to replace dung in many situations.

Composition of Mosses.

Hoffmann has analyzed a variety of mosses such as are sometimes used as substitutes for straw for bedding animals. He found in the air-dried materials 14 to 18% of water, 2 to 6% of ashes, 78 to 84% of organic matter, and from 1 to 1½% of nitrogen. The ashes were rich in potash and phosphoric acid. One sample of ash contained as much as 6% of phosphoric acid, and in two samples there was contained 3%.

Sawdust and Tan Bark.

In connection with straw, a few words may be said with regard to sawdust and to spent tan bark, which often suggest themselves to the farmer as fit materials for the bedding of animals and for the preparation of compost. Speaking in general terms, neither sawdust nor tan bark can be very strongly commended. They do not contain enough fertilizing matters to make them valuable as manure, and they are distinctly inferior to straw, leaves, sods, and peat as materials for compost, or even for mulching, though there are, of course, some particular instances in which they can be made to serve a good purpose.

Tan bark is very well adapted for mulching fruit trees and strawberries in many cases, and dry sawdust is superexcellent for bedding cows, since it keeps them perfectly clean, and is light and easily shovelled, and readily spread in the fields. Experiments are

recorded on a subsequent page which show that dry sawdust can absorb some three times its own weight of liquid. But on this very account the material is not much esteemed for bedding horses, since it is supposed to make their hoofs dry and brittle, and since horse manure charged with much sawdust is particularly liable to spoil in process of fermentation, because the heaps are so light and dry. Even cow manure admixed with sawdust may firefang, like horse manure, in the course of a fortnight, if left in a large heap. It is well to haul it out as fast as it is made, and to leave it in small heaps on the fields to which it is to be applied.

It is not improbable that sawdust may sometimes play a more important part in compost heaps made with cow manure than was at one time supposed, for practical experience has shown that sawdust serves very well for fermenting bone-meal when the two substances are mixed in equal weights and kept in a moist heap; and since it has been found that the nitric ferment needs large amounts of carbonaceous food in order that it may prosper, there is good reason to believe that sawdust may serve a useful purpose in composts by feeding this organism, provided moisture and an ample supply of oxygen are likewise available.

The question of the chemical composition of sawdust, tan bark, and leached dyewoods has been treated of at considerable length in an article in Vol. II. p. 26 of the Bulletin of the Bussey Institution, to which the reader is referred.

Sawdust is poor in inorganic constituents, though in respect to nitrogen it contains more than straw. Indeed, the best use for sawdust (agriculturally speaking) is for feeding animals, care being taken, of course, to sift out all splinters and lumps, such as knots.

Spent tan is poor in everything, and is practically useless, except as a mulch, or for altering the texture of soil.

The following table of comparisons is from the Bussey Bulletin, Vol. II. p. 50.

Per Cent of	Saw-dust.	Spent Tan.	Straw.	Eel-grass.	Twigs with Leaves.	Best Autumn Leaves.
Potash . .	0.10	0.08	0.50 to 1.00	1.02	0.88	0.10 to 0.50
Phosph. Acid	0.05	0.04	0.20 " 0.30	0.23	0.33	0.06 " 0.30
Nitrogen . .	1.00	0.16	0.33	1.30	1.28 to 2.84	0.75

CHAPTER XVII.

HUMUS, OR VEGETABLE MOULD.

The importance of humus as a source of nitrogen is most conspicuous when wild plants are considered. It is from the humus of the soil that forest trees and most of the other natural plants, including grasses, derive the greater part of their nitrogenous food.

Some nitrogen, indeed, comes to all land with the rain and dew that fall upon it. But the amount of this atmospheric nitrogen brought down by rain is comparatively small, and is, by itself, no more than sufficient to nourish a sparse vegetation, or vegetation of a very low order. Some assimilable nitrogen, in the form of nitrates, is found in the waters of brooks also; and the plants which have access to such waters profit by the nitrates that are contained in them, as will be shown under the head of Irrigation. But only comparatively few plants are so situated that they can be nourished by brook-water; and, besides, a good part of the nitrogen in such water is derived, doubtless, from the oxidation of humus, up the stream.

As has been shown, some free nitrogen from the air is oxidized by electrical discharges, and as an incident to combustion, and so made available for feeding plants. But the fact remains, nevertheless, that humus must be looked to as the chief source whence nitrogenized food is supplied to all the higher kinds of wild plants.

Fixation of Free Nitrogen from the Air.

Beside the formation of humus through the decay of plants, which is, practically speaking, the most general and the most conspicuous source of this substance, the researches of Berthelot have indicated that nitrogenized organic matters — such as must for the present be classed with humus — are formed by fixation of free nitrogen derived directly from the air. Berthelot maintains, first, that small quantities of free nitrogen from the air are slowly but continually fixed by vegetable matters in the soil, under the influence of feeble, silent electrical disturbances, such as occur constantly everywhere upon the earth's surface. Secondly, he has performed experiments which go to show that in clays and clayey soils, during

the growing season, there is a slow but incessant fixation of free nitrogen from the air due to the presence of microscopic organisms in the soil.

This fixation of nitrogen, dependent upon microdemes, occurs both in daylight and in darkness, though more freely in the light. It is immediately put an end to on heating the soil to 212°, so as to destroy the organisms; and it does not occur in winter. Berthelot reckons roughly that 25 lb. or more of nitrogen to the acre of land may be fixed in this way in a year. These experiments are manifestly of very great scientific importance, and they are doubly interesting in that they mark a decided step forward in a long series of observations which now serve to support them, or even to verify them.

It was maintained long ago by several observers, among others by De Saussure, that, under certain conditions, a part of the nitrates which form when vegetable matters decay come from the free nitrogen of the air. Other observers urged that the large quantities of nitrates sometimes produced on chalk cliffs which contain but a trace of organic matter point to the truth of the conception that some of the nitrogen in these nitrates must have come from the air. Faraday observed that almost all solid substances exposed to the air contain more or less nitrogenous matter, and his observation has been repeatedly verified and illustrated. Mulder in his day urged with much force, that, when decaying humus undergoes oxidation by the action of air, some of its hydrogen unites with nitrogen from the air to form ammonia [or some other nitrogen compound]. He supported this view primarily upon experiments which showed that moulds grown upon non-nitrogenous substances always contain protein. Thus, on leaving for three months dilute aqueous solutions of sugar in stoppered bottles with a sevenfold volume of air, an abundance of mould grew, which, on being collected and subjected to dry distillation, gave off large quantities of ammonia. So too, starch kept under water in a bottle that contained air soon fermented, and the fungus which it had nourished gave off ammonia on being distilled; and in like manner woody fibre, decaying with scanty access of air in the lower layers of a vegetable soil, appeared to form ammonia, because part of the hydrogen of the fibre combined with nitrogen from the air, while another part combined with oxygen.

In other experiments, Mulder grew bean plants in soils that consisted either of ulmic acid (made from pure sugar) or of charcoal,

with which 1% of ash ingredients had been admixed, and which were watered with pure water. He found twice and thrice as much nitrogen in the bean plants as was contained in bean seeds similar to those which he had planted. From all of which a view obtained currency many years ago that ammonia is generated when nascent hydrogen from decomposing organic matters comes in contact with the free nitrogen of the air. Indeed, it was taught at one time that nascent hydrogen from water that is undergoing decomposition by the action of metals, such as zinc or iron, which remove oxygen from it, could unite with free nitrogen to form ammonia. But this idea was disproved by the experiments of Will.

In certain experiments of Boussingault (see "How Crops Feed," p. 259), the amount of nitrogen contained in garden loam was found to increase slightly during the summer months, although at the very time the carbon in the soil was wasted to an appreciable extent by oxidation. But in soils which had been deprived of organic matter no appreciable accumulation of nitrogen occurred. Experiments by Cloez also on nitrification ("How Crops Feed," p. 263) point to fixation of free nitrogen from the air by the materials upon which he operated.

Koenig and Kiesow, in their experiments on the prevention of loss of nitrogen during the decay of organic matters, noticed that, instead of losing nitrogen in the course of the experiments, the substances usually gained a little of this element, especially when gypsum and loam were present. But the amount of this increase was so small that it was attributed to errors inherent in the method of experimenting. In these experiments the materials were mixed with water to a pap which became strongly alkaline through fermentation.

Armsby (American Journal of Science, 1874, VIII. 337) exposed decaying nitrogenous organic substances, that were "moist, but not coherent," to a current of air, and observed that usually small amounts of nitrogen were lost from them, except in those instances in which the organic matters had been made alkaline with potash. Here he noticed distinct gains of nitrogen. In Armsby's own words: "We must conclude that decaying organic substances, in the presence of caustic alkali, are able to fix free nitrogen without the gain being manifest as nitric acid or ammonia, and probably without the formation of these bodies." It is to be presumed, of course, that fermentations favorable for the fixation of nitrogen were promoted by the alkali, — potash in this case.

Contemporaneously with these observations, Selmi showed that moulds and other fungi, both visible and microscopic, evolve hydrogen, especially from those parts which are in the shade. Ordinarily, or, so to say, normally, most of the hydrogen produced by the larger fungi combines with oxygen from the air to form water. But at the same time a little ammonia [or other compound of nitrogen] is formed by the union of some of the nascent hydrogen with nitrogen from the air. Selmi argued at once that this fact is one of much agricultural importance.

Many years after Mulder, Dehérain, returning to his idea, mixed humus taken from old trees with a solution of carbonate of potash, and heated the mixture in a closed flask that contained a mixture of oxygen and nitrogen. He found that, while all the oxygen went into combination with the organic matters, an appreciable quantity of nitrogen also was absorbed. Whence he argued, that organic matters decaying in the soil absorb some nitrogen, as well as much oxygen, and so act to make a part of the nitrogen of the air available for feeding plants.

In other experiments, made at the ordinary temperature of the air, he found that the presence of oxygen seemed to hinder the fixation of nitrogen, and he argued that this would naturally be the case, since, when oxygen is present in abundance, it would combine continually with the nascent hydrogen and allow very little chance for nitrogen to do so. But on exposing wet sawdust, with or without lime, humus from old trees, or, best of all, mixtures of glucose and soda, to nitrogen gas, instead of ordinary air, it usually happened that some of the nitrogen was absorbed and fixed. There were formed nitrogenized compounds that were capable of yielding ammonia on being ignited with soda lime. It appeared in these trials that the fixation of nitrogen by carbonaceous matters can occur even at the ordinary temperature of the air, though more readily at higher temperatures. According to Avery, mixtures of glucose and dilute solution of soda ferment readily when seeded with the lactic ferment and heated. They yield hydrogen freely, as well as lactic acid.

Still later, Dehérain tried experiments with sawdust, humus from old trees, decomposed wood, and glucose mixed with lime, potash, soda, or ammonia, and often found that appreciable quantities of nitrogen were fixed from the air, notably in cases where the old wood and the humus were employed. He found, as before, that

the presence of oxygen was detrimental, and agreed with Mulder that nitrogen from the air can perhaps be more readily fixed in the lower layers of the soil than near the surface, where oxygen is abundant. He urged anew that fermenting or decaying organic matters, such as occur naturally in the soil, evolve hydrogen, which, when nascent, unites with free nitrogen from the air to form ammonia, which enters into combination with carbonaceous matters to form substances analogous to those naturally produced in the soil by the decomposition of vegetable matter.

With the advance of knowledge, the results of all these experiments have become much more intelligible, since it is now evident that they must have been brought about by the action of ferments. That is to say, the reactions described depended on biological, rather than upon chemical conditions. Several years ago, my friend, Mr. C. E. Avery, while working out his patented process for making lactic acid in the large way, was impressed with the idea that nitrogen compounds are continually formed by the union of free nitrogen from the air with the nascent hydrogen which is known to be developed during many kinds of fermentations. Under date of February 20, 1885, he wrote to me the following statement: "In my fermentation studies, it seems to me that the source of the nitrogen supplied to plants is plain: all the steps are now proved, we only want the experimental link. The nitric ferment, when air and calcic carbonate are present, oxidizes ammonia to nitrates, the direct food of plants. The ammonia is known to form whenever nascent hydrogen is released in the presence of free nitrogen, that is to say, of air. Now when glucose or lactic acid, or many other vegetable bodies ferment, nascent hydrogen is released as in the butyric fermentation,

$$2\,C_3H_6O_3 = C_4H_8O_2 + 2\,CO_2 + H_4.$$

But, as appears from pages 583 and 584 of Vol. III. Part II. of Roscoe and Schorlemmer, pine wood, poplar wood, and lignin yield glucose in fact in presence of water, albuminoids, and nutritive salts. Wood is well known to ferment rapidly, to its destruction, — the starch, inulin, sugar, etc., in it adding to the amount of hydrogen which is set free. Have we not here a complete chain of known facts, and a theory of the old barnyard plan of manuring? Many other ferments beside the butyric release hydrogen. See Schützenberger, for example, in his book 'On Ferments.'"

In a subsequent letter, dated March 22, 1885, Mr. Avery insisted

that experiments tried by himself upon loam clearly indicated the occurrence there of fermentations, such as occasion the evolution of hydrogen. His words were as follows: "I have run two fermentations of garden soil, from flower-pots, in contact with calcium carbonate, with supernatant water at 110° F., and find that carbonic acid comes off lively. Hence lactic and butyric ferments are almost certainly present; also glucose yielders." And, alluding to the observation of Zabelin ("How Crops Feed," p. 80), that ammonia is formed upon bits of paper or linen (i. e. cellulose) wet with water and heated in the air to from 120° to 160° F., he added, "I have myself found that in faintly alkaline solutions these fermentations run well at what are usually thought to be killing temperatures."

It should here be said, that the argument set forth on a previous page, that clover or other leafy crops may perhaps favor the growth of the microdemes which cause nitrification, will probably enough apply with even greater force to fermentations in the soil caused by the organisms noticed by Berthelot which give occasion for the fixing of nitrogen from the air.

In the light of existing knowledge, it may be regarded as proved that some nitrogen from the air is really fixed as an incident to certain fermentations which occur in the soil. The fact is one of the utmost importance when geologically considered, and it may possibly prove ultimately to have considerable agricultural significance, even in the immediate economic sense. The fact that any nitrogen can be fixed in this way is manifestly sufficient to explain a phenomenon which has been several times observed, viz. that plants, especially legumes, grown in pure sand with addition of chemicals and distilled water, do sometimes acquire, as if directly from the air, a larger amount of nitrogen than was contained in their seeds and in the food that was purposely supplied to them. For, in case the germs of organisms, such as those indicated by Berthelot, should gain access to the sand, some nitrogenous food would in due course be supplied to the plants growing in this sand. (Compare Atwater, in American Chemical Journal, February, 1885, VI. 365.)

Humus a Reservoir of Nitrogen.

One of the most important attributes of humus as found in fields and in swamps depends upon the fact that it is a reservoir of nitrogen, which has been accumulated upon the land by the generations of plants which have lived and died there.

The lichens or mosses which appear upon the bare rock with the first suggestion of disintegration, as well as the hardy plants that succeed them, all accumulate nitrogen from the waters by which they are nourished, — much as the swamp mosses accumulate it to be stored in peat; and they yield after death a nitrogenized humus which tends to increase in quantity in temperate climates as long as the land or bog is left under the natural conditions, i. e. covered with vegetation, and neither exposed to fires nor to the denuding action of water. In all such cases the humus appears to have accumulated in the places where it is found, by virtue of plant-food which has been gradually brought to those particular spots from other localities by means of water.

The Character of Humus varies with the Climate.

Humus may assume very different conditions, according to climatic and other circumstances to which it is exposed. But the fact of its accumulation in countries that are neither too hot nor too dry is none the less a general fact. In temperate climates peat is often formed, while within the tropics peat is said to be unknown, except upon high mountains at an elevation of several thousand feet above the sea level.

In hot climates the surplus humus sometimes collects in enormous beds of black mould of extraordinary fertility. But in cold high latitudes, on the other hand, the tendency is to form moorland rather than peat-beds, at least in many situations; and there are thousands of miles covered with a deep black humus, rich in nitrogen it is true, but cold and sour, and wellnigh unfit for the support of plants. A somewhat similar product occurs in New England as a cold, sour black earth found at the tops of high hills.

Besides differences so radical as these, a great variety of products is necessarily comprised within the meaning of the term "humus," since the substances which result from the decomposition of organic matters differ from one another materially, according as the decomposition has been slow or rapid, and as it has occurred in heaps or beds, or in the manure heap, in the soil, or under water. As here used, the term "humus" includes peat and swamp muck and vegetable mould, and the organic portion of all the earth-like products that result from the decay of vegetable or animal matters.

Conditions favorable for forming Humus.

It is to be noticed that the circumstances which favor the formation of humus are somewhat peculiar, as regards access of air and

moisture. If the decaying vegetable matter — say the leaves of trees — were but supplied from the first with an excess of air, and kept somewhat moist and warm, it would soon oxidize completely to carbonic acid, water, free nitrogen, ammonia, and nitrates. It would be consumed, in fact, as if by fire, so that nothing would be left upon the land but a little ashes. But under the conditions which actually obtain in temperate or cold climates, the leaves, or what not, accumulate in damp beds, thanks to the action of wind or flowing water, or they are buried more or less completely beneath other leaves; so that the supply of oxygen that reaches them is limited, and the process of combustion is checked far short of the final products of which mention was just now made.

In case the vegetable matter is immersed wholly or in part in water, so much the slower will the oxidation be. But in warm open air the reactions are very different. For example, Mr. Smith, in describing the great forests on the Amazon, writes as follows: —

"How are the trees nourished? The ground is sandy, as it is almost everywhere along the Amazons, and not very rich; it is nearly bare above, for mould does not form in the tropics, except about swampy places. At the North the leaves fall together, and rot under the snow; but here they drop one by one, all through the year; they dry up, are broken to dust, and so pass away in the air. Fallen logs and branches are eaten by insects. There is nothing left to form a rich soil of."

"In fact, it is a mistake to suppose that all this rampant tropical growth depends on any inherent fertility of the ground. The sun and the moist air [and he might have added, the enormously rapid nitrification] make up for barren soil. Beside the rains, there are the heavy dews, and the winds are always soaked with moisture. The sand has no [visible] richness of its own, but it aids growth by carrying rain to the thirsty roots. Water does not collect at the surface; it sinks at once, and is evenly distributed to a great depth, and in this climate the ground has no chance to dry up."

So too, when land in temperate climates, instead of being left to itself, comes to be cultivated, there will then be in many cases a constant drain upon the humus; and in order to keep up the fertility of the field, there will be need of applying to it new quantities of nitrogen, either in the form of farmyard manure, or of peat taken from some place where humus has accumulated in excess. It is recognized nowadays that the farmers are wholly right in

state in proportion as they contain ly, less of the silica is precipitated tion as it is richer in humus.

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Good in several Ways.

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bring about disintegration and solution soil doubtless depends upon a variety of very evident that it must be of great importance of nature. Many facts might be cited in For example, Peters found that, while a soil containing ferric phosphate had no sing the amount of phosphoric acid that water, it nevertheless increased the solubility materially when left in the soil long enough on, and so reduce a portion of the ferric of a ferrous salt. The experiments of Stoeck-red to when speaking of the waste of humus rly exhibit the solvent action of humus. A filled with sandy loam; the loam in some of in various proportions with humus from a es, and upon the soils thus prepared ray-cultivated. In some of the boxes hot-water that the temperature of the earth could be

soluble in water, and their compounds occur, in small proportion it is true, in all fertile soils. They probably have no inconsiderable influence upon the growth of plants, although nothing is known as to the manner of their action.

The Humic Acids have considerable Chemical Power.

The humic acids, as they are often called collectively, exhibit considerable chemical activity. Eichhorn has shown that mixtures of humic and ulmic acids, and sour peat also, can decompose dilute solutions of the chlorides of potassium, sodium, and ammonium, and of other neutral salts, and set free the chlorhydric or other acid which the salt contained; so that sour earth to which a neutral salt has been added may become more acid than it was by itself. No such acidification occurs, however, when the peat or other earth examined contains no free humic acid, but only humates.

Reactions analogous to those with the chlorides occur when bone phosphate of lime or another phosphate is mixed with free humic acids, though the decomposition of the phosphate never goes very far. The reaction is promoted by the presence of neutral sulphates, such as those of the alkali metals. Naturally enough, all these reactions are hindered by the presence of substances, such as marl, lime, and manure, which work to neutralize free humic acid.

It has been insisted by Vogel, that plants growing in soils rich in silica but poor in humus generally take up much less silica than plants growing in soils rich in humus even though poor in silica. He holds that good loam is usually well fitted for supplying silica to plants, the inference being that the humic acids of the organic matter act upon silicates in the soil slowly to decompose them and supply to the plant roots some form of soluble silica. Vogel claims that the presence of much silica in sedges and the other inferior herbage of swamps depends upon the abundance of humus in such situations. The suggestion is an interesting one, as pointing to the probable action of humic acids on many inert combinations in the soil to set free from them inorganic foods of one kind or another for the use of crops. Compare Grandeau's observations on the presence in loams of soluble compounds of ash ingredients and organic matter.

Considered as a reservoir of acids, humus is doubtless stronger than soluble silica, in the sense that it can combine with bases so firmly as to hold them against this competitor. It has been noticed, that, other things being equal, soils can "fix" more silica that is

added to them in the soluble state in proportion as they contain less humus; and that, conversely, less of the silica is precipitated and retained by a soil in proportion as it is richer in humus.

Beside the compounds above enumerated, humus contains the obscure nitrogenized matters which have been so often referred to, and no one knows how many other things beside.

Humus may do Good in several Ways.

It is to be observed, that the value of humus as a manure depends upon a variety of properties. In the first line, no doubt, must be placed its power of supplying nitrogen to the plant.

Then, by virtue of its porosity, it imbibes and absorbs and holds water, and the vapor of water. By its lightness, too, it improves the texture of many soils. And it absorbs and holds ammonia and the salts of ammonia, as well as various other substances.

It promotes chemical action in the soil, both by means of the acids contained in it, and by those of the character of crenic and apocrenic acids which are formed by its decay. Moreover, by its slow decay, humus supplies carbonic acid for the dissolving of plant food, as has been explained before.

Some of the materials rich in humus, such as marsh mud, harbor mud, and pond mud, may even be valuable occasionally because of the inorganic constituents which are contained in them.

The power of humus to bring about disintegration and solution of mineral matters in the soil doubtless depends upon a variety of circumstances. But it is very evident that it must be of great importance in the economy of nature. Many facts might be cited in illustration of this point. For example, Peters found that, while the addition of humus to a soil containing ferric phosphate had no immediate effect in increasing the amount of phosphoric acid that could be washed out with water, it nevertheless increased the solubility of the phosphate materially when left in the soil long enough to undergo decomposition, and so reduce a portion of the ferric phosphate to the state of a ferrous salt. The experiments of Stoeckhardt also, already referred to when speaking of the waste of humus in cultivated fields, clearly exhibit the solvent action of humus. A number of boxes were filled with sandy loam; the loam in some of the boxes was mixed in various proportions with humus from a grove of old beech-trees, and upon the soils thus prepared ray-grass and maize were cultivated. In some of the boxes hot-water pipes were placed, so that the temperature of the earth could be

kept continually 8° or 10° C. higher than that exposed to the ordinary summer air.

It appeared that the following quantities of materials had been made soluble in the course of the three summer months, by chemical action in 25,000 grm. of earth.

Grams of	Earth rich in Humus. Ordinary Temp.	Heated.	Earth poor in Humus. Ordinary Temp.	Heated.
Lime	7.78	7.23	11.57	13.63
Magnesia	3.30	2.44	0.00	1.97
Potash	5.88	8.60	5.11	4.12
Phosphoric acid	3.11	6.02	3.36	1.64

Humus often improves Tilth.

Humus has undoubted value for lightening and mellowing heavy clays, and conversely for binding sands. It may act in the first instance to lighten a heavy soil in the same way that any coarse manure, such as straw or partially rotted chips, sawdust, or tan bark would act, as will be urged when composts are treated of. But there is another finer, more intimate and enduring action which humus shares with clay, that is of far greater importance for the permanent fertility of the land.

As has been shown under the head of Tillage, it is necessary, in order that a soil may be fertile, that its particles shall be granular enough to permit air and rain to circulate freely among them. This needful coherence or granulation of the particles of loam is assured by the presence in fit proportion of humus (or clay), which — while itself protected from being puddled by the presence of lime and other saline matters which are dissolved in the soil-water — acts to cement or bind together the fine rock particles or sand which is the other constituent of the loam. This subject has been studied by Schloesing, as follows: —

First, he prepared mixtures of pure sand and pure moist clay, that contained respectively 1, 5, 10, 15, and 20% of clay, and left them in the air until they were dry enough to crumble between the fingers.

Upright tubes, at the bottoms of which had been placed bits of glass covered with coarse sand, were filled with the crumbled mixtures, and a layer of cotton was placed on top of each of them. Water that contained 2 or 3 ten-thousandths of a lime salt was then made to fall very slowly upon the cotton, drop by drop, or rather in the form of fine spray, during 3 or 4 days. Under this treatment those mixtures of sand and clay which contained less

than 10% of the clay did not retain their original appearance or their looseness; while the mixtures that contained 15% of clay remained practically unaltered. New mixtures were then prepared that contained respectively 10, 11, 12, 13, 14, and 15% of clay, and treated as before, with the result that 11% of clay from Vannes was competent to hold the sand in granules against the action of the water.

When chalk was substituted for the siliceous sand, rather more of the clay than 11% had to be used to hold it together; and, in general, more of some kinds of clay than of others was needed for binding sands. The power of the clays seemed to stand in direct proportion to their plasticity.

It appeared, furthermore, that natural loams which contained no more than 5 to 10% of clay retained their porosity when subjected to the action of the water in the above-mentioned tubes, whence it was plain that such soils must contain some other binding material beside the clay. That this other material is humus appeared from the following experiment.

Some loam was leached with dilute chlorhydric acid, to remove lime and the other bases with which the humus had been combined, and then treated drop by drop with alkaline water to dissolve the humus. So long as the acid was present, no change in the appearance of the loam occurred; but the moment the humus began to be dissolved by the alkali the coherence of the loam was destroyed, and all of its constituents (of which the humus formed but a small portion) fell down to an impenetrable layer of mud.

It was noticed that the destruction of the granular condition of the loam kept pace with the solution of the humus by the alkali; whence the inference that the compounds of humus are colloids competent to act as a kind of glue to cement the particles of earth together. This observation consists withal with the popular belief that humus serves to bind light soils, and to make them firmer.

To test the matter still further, Schloesing prepared humates of lime, iron, and alumina, and made mixtures of them when moist with sand and lime. The following mixtures, from which clay was wholly excluded, were treated with water in tubes as above described:—

	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Sand	99	82½	66	0
Lime	0	16½	33	99
Humate of lime	1	1	1	1

All of them withstood the action of water, even that of distilled water, whence it appeared that a single part of humate of lime was as effective as eleven parts of the Vannes clay to cement the sandy particles.

When these mixtures that contained the humate were moulded into little balls and cylinders, and allowed to dry, they became so hard that they could be thrown upon the floor without breaking, though it was found in general that, when but a small proportion of a humate is admixed with much sand, as in the first column of the figures, the cementing power is somewhat impaired by drying.

Other mixtures of sand and lime that contained 4 or 5% of clay together with 1% of humate of lime or humate of alumina likewise resisted the action of water, the general conclusion being that the humates are better able than clay to bind together particles of sand.

On the other hand, the following experiments, likewise by Schloesing, go to show the justice of the popular opinion that humus lightens heavy soils. He kneaded pure clay with water, together with additions of humus compounds, into mixtures that contained respectively 2, 4, and 6% of the humate, and found that all of them, as well as pure clay, became very hard on drying, one lump being apparently as hard as another. But on bringing the lumps into contact with water they behaved very differently. All of them fell down to the condition of mud, but when the muds were left untouched until dry, the resulting powders were found to be less coherent in proportion as they contained more humus. By direct experiment, it was found that many good soils contain enough humus to bring about the effect just described.

When clay coagulates or flocculates, it can enclose considerable quantities of humus. But more of the coagulating agent (see under Lime) has to be used to coagulate clay that is suspended in an alkaline solution of humus in proportion as the amount of humus contained in such solution is larger. Thus, while from $\frac{1}{1000}$ to $\frac{2}{1000}$ of potassium chloride will coagulate pure clay that is suspended in water as much as from $\frac{10}{1000}$ to $\frac{20}{1000}$ would be required, if together with the clay 100 to 200 milligrams of humic acid were contained in a litre of water.

In practice, peat has sometimes been found to do good service on drained clay soils, and a part of its utility may justly be referred to this power of lightening the clay. It has been noticed that peat

waters strongly colored with organic matter sometimes become clear on passing over beds or through banks of clay, though it has been suggested that clays which are slightly acid (from the presence of sulphate of alumina) are specially effective.

Humus retains Moisture.

The power of humus to retain capillary water has already been strongly insisted upon. It is on this account also that humus is so important in sandy soils. Indeed, there are few soils that can dispense with this peculiarity of humus, excepting those which are irrigated or in which the depth of the ground-water is constant and perfect. Here in New England, upon the drift gravel, manures rich in humus will always be preferred to the so-called chemical fertilizers on this account.

The estimation in which peat is held by practical farmers, both as a manure by itself and as a "body" for composts, illustrates this point, perhaps, more forcibly than anything which can be urged from the scientific point of view.

It is sufficient to look in dry summer weather at a gravelly field manured with peat compost, and contrast the vigorous vegetation upon it with the dried-up crops of the neighboring fields, to be convinced of the power of humus to "draw water." Such fields suggest the thought that there may be such a thing as mulching below the surface as well as upon the surface, and they well illustrate the significance of the hygroscopic power of peat in the sense of Hilgard's observations.

In former years the agricultural newspapers were accustomed to bear frequent witness to the great value of peat, and the manures of which it forms a component part. Some sanguine observers have even gone so far as to allege that the best kinds of peat are worth as much, load for load, as barn-yard manure. Prof. Johnson, of New Haven, has collected a considerable amount of this kind of evidence, and published it in his excellent little manual on "Peat and its Uses."

It is true, no doubt, that some kinds of peat are really manures which may be applied to the land at once. They may afford excellent crops, even when used in the absolutely fresh condition, without any preparation whatsoever; but such superexcellent specimens are very rare. Most kinds of peat are not easily putrescible, and, as a general rule, peat needs to be weathered or seasoned, or even fermented, before it can be profitably used as a manure.

Crude Peat is Sour.

Indeed, there is a common opinion that the application of raw peat to a cultivated soil may do actual harm, and it is not improbable that this opinion is well founded. Most peats do possess a certain antiseptic or germicide quality, when freshly dug, which would be likely to hinder nitrification as well as the other forms of fermentation and decay. Not infrequently mud taken from swamps and bogs, sometimes even pond mud (Link), contains iron pyrites (FeS_2), which oxidizes readily on being exposed to the air, and forms the soluble salt called copperas or sulphate of iron ($FeSO_4$), as has been said already. Peats which have become thus charged with sulphate of iron are poisonous to agricultural plants, and to the microscopic "ferments" as well.

But even if the crude peat did no damage, it would still be true, and is, in fact, a matter of the commonest experience, that many kinds of raw peat do the land little or no good; and it may be accepted as a general rule, that crude peat is vastly inferior to that which has been mellowed by exposure to the air. Most kinds of peat only show their best power after they have been "seasoned," or, what amounts to the same thing, after they have lain upon the field until the second year from the time of their application. This behavior depends, doubtless, upon chemical changes to which both the nitrogen compounds in the peat and the antiseptic matters are subjected when the peat is exposed to the air.

The popular notion that there is an "acidity" in peat which is corrected by age and by exposure to the weather, is merely one way of indicating the presence of the antiseptic matter. So too the idea of acidity includes the cases in which the peat is sour from containing sulphate of iron.

Beside the changes induced in the nitrogen compounds by aeration, the chief use in leaving raw peat exposed to the air for some months before using it is to get rid of the great quantity of water that adheres to it, and to make the lumps "mellow" and friable; or, in other words, to have the mechanical texture of the peat improved by repeatedly freezing and thawing it.

Even though there might be no great harm in applying peat to the land as soon after digging it from the bog as was convenient, there would, generally speaking, be no sense in thus applying it, because no useful effect would be got for a whole year, in the majority of cases. It is possible, moreover, that the useless peat might

do harm by interfering with the action of other fertilizers. For it might combine with these fertilizers to form insoluble double humates at a time when they had better not be formed, and it might check the action of the nitric ferment. The true way of employing peat is in the form of "compost," as will be explained hereafter.

Mild Humus as a Solvent.

In addition to the mechanical and chemical effects already alluded to, there is no doubt that some of the better kinds of humus may have considerable influence by directly promoting the solution of plant-food. Grandeau in particular has insisted, perhaps rather too strongly, upon this point. He maintains, that in Russian black earth and in other rich loams of high fertility, i. e. in garden loams and in barnyard manure also, there is a peculiar organic substance which combines in a very peculiar way with phosphoric acid, lime, magnesia, oxide of iron, and silicic acid.

To obtain this material, Grandeau directs that loam should be leached with a dilute acid to remove the bases with which the organic matter is naturally combined in the soil; that the excess of acid should be removed by washing the leached loam with water, and that the residue should be treated with ammonia water. The black matter will then dissolve at once in the ammonia; and in this solution will be contained phosphoric acid, lime, magnesia, iron, and silica, although neither of these substances can be detected there by means of the ordinary chemical tests. The presence of each and all of them, as well as that of potash and manganese, may readily be exhibited, however, by evaporating the solution to dryness, igniting the residue, and subjecting the ashes to analysis. Moreover, on dialyzing the ammoniacal solution, i. e. on placing between it and pure water a membrane so arranged that osmotic action may occur, it is found that the inorganic substances now in question readily pass through the membrane into the water, while the black matter remains behind. In the course of 36 hours, 86% of all the ash ingredients contained in such a solution passed through the membrane, while the water into which they diffused remained colorless and free from carbonaceous matters. Thus, presumably, would the constituents needed by plants pass into them by way of osmosis out of the organic solution. As obtained from some soils, Grandeau's black matter may contain no more than 2% of ashes, while in other instances it may yield 60%.

It would appear from the foregoing, that, under some circumstances, ammonia-water may dissolve from the soil phosphoric acid, lime, etc., that is, in so far as they are held in soluble combination by the organic matters. Indeed, carbonate of ammonia, such as might occur naturally in soils and manures, is better than ammonia-water, because it can act directly. Its carbonic acid combines with the lime which in the soil ordinarily holds the black matter in the soluble state, and so permits it to dissolve in the ammonia. From Russian black earth, which contained 0.2% of phosphoric acid, 80% of this particular constituent was extracted in organic combination by means of ammonia-water.

Grandeau is of opinion that carbonate of ammonia is of great importance as a solvent of food for crops. He believes that by means of it, acting in the manner above described, both farmyard manure and many fertile soils may afford soluble inorganic food to crops, — the organic matter acting as a vehicle, so to say, for the transportation of the ash ingredients. He urges, furthermore, that the fertility of soils is intimately connected with the amount of mineral matters that are contained in them so combined with organic matter that they can dissolve in ammonia. In barren moor earth he found no more than mere traces of such materials, while Russian black earth was surcharged with them, and they were abundant in fertile garden loam and in woodland humus.

Too much Humus does Harm.

There is no need to say, that the very qualities which make humus so valuable in soils that are naturally too dry, unfit it for application to moist soils. There are few things worse than humus upon a wet soil. In case any large quantity of it were put upon a moist soil, it would remain wet and cold, and would tend to increase the bogginess of the place.

Whenever a field becomes surcharged with stagnant water, no matter from what cause, it will ultimately become covered with the coarse, innutritious vegetation that delights to grow with its roots immersed in water.

A curious instance of an unwished for accumulation of humus has been noticed in Germany in connection with experiments upon a now somewhat noted method of cultivating moorland by covering it with gravel. This method, which has excited a great deal of attention of late years, is applicable to bog meadows where there is a good depth of black earth; i. e. where the layer of peat or moor

earth is from a foot and a half to three feet or more thick. The operations consist in digging deep, wide ditches at stated intervals, and spreading upon the surface of the moor the sand or gravel which is taken from the bottoms of the ditches. Upon this thick layer of gravel the crops are grown.

Cases have been described where the ditches were dug at distances of about 75 feet one from another; they were 16 feet wide at the top, 11 feet wide at the bottom, and 4 or 5 feet deep. The black earth from the ditch is first spread upon the surface of the moor, and then the sand, gravel, loam, or clay taken from the bottom of the ditch is spread, in its turn, so that a layer of it four inches thick shall everywhere cover the moor earth. A gravelly sand is said to be best; and, in general, the more gravelly the subsoil is, the better, provided it contains some clay. Pure fine-grained quartz sand is said not to answer nearly so good a purpose as gravel.

Oats may be sown at once upon the layer of gravel, and afterwards potatoes, roots, grain, and all kinds of forage plants. The main point is, that the layer of gravel is left permanently upon the surface of the land. It is never ploughed under, nor mixed with the moor earth. But from time to time, when the surface land seems somewhat hard or incrusted, a subsoil plough is run through the beds, so as to loosen the soil without mixing one layer with another.

One prime purpose of the layer of gravel is to shield the young crops from night frosts in the spring. The gravel lessens the evaporation of water from the soil, and it hinders the radiation of heat also, and thus keeps the land comparatively warm. The objection to fine sand is, not merely that it is blown away by the wind, but that it dries too rapidly by day and chills too quickly by night. Besides all this, the gravel layer compresses the moor earth, which would be apt to become too light and dry if it were cultivated directly in the ordinary way, and exposed to sun and wind.

It is to be understood, of course, that the moor must be well drained before this method of cultivation, or any other, can be adopted. It has been found in practice that this method of reclaiming moorland yields better crops than can be got from the moors by any other known process, and that the effects of the reclamation are sure and lasting. Whether or not it is the most economical of known methods is of course a totally different question.

Analysis had shown from the first that the crops grown upon moorland thus reclaimed are particularly rich in nitrogen; and, after some years' experience, it began to be noticed in certain localities that grain crops are apt to lodge badly on beds that are 8 or 10 years old, and it appears that the trouble comes from too great fertility of the soil, i. e. from the accumulation in it of too much nitrogen. The practice had been to manure the fields much as any upland field would be manured, and here is where a mistake seems to have been made, for by using stable manure too much humus accumulates in the gravel layer.

Osswald, who has examined the soil from a number of these gravelled moors, found that the surface layer of gravel had become charged with a large amount of organic matter. Not that the gravel and the moor earth from below had become mixed. On the contrary, the line of demarcation between the two kinds of earth is said to have been surprisingly sharp, considering that twelve years had elapsed since the gravel was spread, and that arable crops had been grown upon the land continually. The trouble was, that the continued application of stable manure and the accumulation of plant roots had led to an actual accumulation of humus in the gravel.

Osswald did not find any surprising amount of nitrates, though he did find very large quantities of ammonia, and it was plain that there was present a far larger quantity of active nitrogenous manure in the soil than there was any need of. As the lodging of the grain had already shown, there was far too much of this nitrogen. Instead of becoming exhausted with cropping, the fields had become too fertile. That is to say, they were no longer competent to grow so great a variety of crops as they had been at first. They still did very well for grass, however. Some of the twelve-year-old beds yielded the best crops of ray-grass, cut over and over again for green fodder, they had ever given, though they had all along been well manured with dung, superphosphate, bone-meal, and Stassfurt potash salts.

Speaking in general terms, the continued use of dung on such land was manifestly an error. Here assuredly, if anywhere, the exclusive use of mineral fertilizers would be in order. Here, if anywhere, the farmer could put his trust almost exclusively upon the stores of natural nitrogen. It was noticed long ago by German cultivators, even on bog lands that have not been covered with

gravel, but merely mixed therewith, that much more abundant crops of forage can be grown than of merchantable grain, and that it is not good practice to apply heavy dressings of dung to such land, because of the rank growth caused by it. Dressings of marl, used in conjunction with phosphatic and potassic fertilizers, have been commended for such land.

When gravel-covered bog-land has become surcharged with humus, as in the case just now described, it would seem proper that a series of exhausting crops should be grown upon it without any nitrogenous manure, in order to take down the exuberant fertility; else a new layer of gravel might have to be laid down on top of the old layer, at enormous expense.

The great cost of covering a bog with gravel in this way limits the applicability of the process to countries where labor is abundant, although it is worthy of remark that cranberry bogs have long been made in this country much in the same way. But there is a modification of the process applicable to moors which are covered with but a thin layer of black earth, which might possibly be applied occasionally even in this country.

When the moor earth is no thicker than from 8 to 16 inches, the Germans get the top layer of gravel by bringing up the subsoil from just below by a system of trench ploughing. Three ploughs specially adapted to the purpose are run one after the other. The first plough turns a flat furrow 3 inches or so deep; the second plough stirs the sole of the first furrow to a depth of 12 or 16 inches; and the third plough throws up at least 6 inches of the loosened gravel, to cover the original sod. The idea is much the same as before, viz. to cover the humus with gravel. These ploughing operations are carried out in summer and autumn. Next spring the furrows are levelled with a heavy harrow, and oats are sown upon the land.

The process is interesting enough and instructive enough to demand attention when considered merely as a method of cultivation; but the purpose of citing it here is to indicate how rapidly humus, i. e. nitrogenous humus, may accumulate in a soil when the conditions are favorable for such accumulation. As bearing upon this point, reference may again be made to the fact of observation, that in ordinary European farm practice only a moderate proportion of the nitrogen applied to the land in the form of manure or fertilizers is recovered in the crops.

Usually the system of cultivation just described appears to answer

an admirable purpose, though, as needs hardly be said, the moor should not be poisonous at the start. The following analyses reported by Maercker relate to moorland that had been covered in the manner first described. Bed No. I. bore good crops; but on bed No. II. nothing would grow from the first; on the contrary, a crust that contained iron compounds formed at the top of the four-inch layer of sand. Bed No. III. gave a good crop of wheat in 1871, but horse-beans failed upon it in 1872. No. IV. was from a wild moor; the sample was taken from a bare spot in a birch wood on which no vegetation had been seen for 25 years.

It appeared from the analyses that all the specimens contained enough potash, lime, phosphoric acid, and other ash ingredients, to have enabled the land to bear crops; but in addition to these things there was a good deal of iron, and in some cases there was the poisonous ferrous sulphate also.

100 Parts of the dry Earth contained	I. Continually Fertile.	II. Not Cultivable.	III. Cultivable at first.	IV. Bare for 25 Years.
Iron, reckoned as ferric oxide (Fe_2O_3)	4.830	7.540	6.580	6.390
Iron in the form of ferrous oxide (FeO)	1.500	1.880	1.780	2.740
Iron that was soluble in the form of ferric oxide	0.226	0.999	0.319	0.066
Iron that was soluble in the form of ferrous oxide	0.000	1.349	0.298	0.395
Iron that was soluble, all reckoned as ferric oxide	0.226	2.498	0.650	0.505

It appears from the analysis No. I. that a small amount of ferric sulphate did no particular harm, while the ferrous sulphate of II., III., and IV. poisoned the land. The analyses enforce the propriety of using bone ash or ground phosphatic guano, greensand, and muriate of potash on such land rather than gypsum, or sulphate of potash, or superphosphates that contain gypsum; for by the reduction of the sulphates in the nonaerated moor earth sulphide of iron could readily be formed, and through the oxidation of this sulphide the poisonous ferrous sulphate might result. Maercker urges that by liming the soil, so that it shall be charged with calcic humates, the noxious ferrous sulphate would be decomposed as fast as it formed.

Carsten, in Holland, tried the experiment of growing oats on contiguous plots of moorland, each $\frac{1}{8}$ of an acre in area, some of which had been reclaimed by covering the land with gravel, as above, while others had been reclaimed by mixing gravel with the moor earth. In every instance where the gravel and moor earth

were admixed, the crops obtained were inferior to those from the gravel-covered land, as will appear from the following table.

Manure on ⅕ Acre.	Cost of the Manure.	Bushels Oats from ⅕ Acre of Covered Land.	Mixed Land.
55 lb. rectified guano			
55 " steamed bone-meal	$4.00	6.13	5.56
33 " sulphate of potash and magnesia			
66 " plain Peruvian guano . . .			
55 " steamed bone-meal	4.25	8.51	6.13
33 " sulphate of potash and magnesia			
33 " nitrate of soda			
66 " steamed bone-meal	3.80	4.26	1.94
83 " sulphate of potash and magnesia			
110 " rectified guano	3.80	9.37	6.81
Same money value of plain Peruvian guano	4.00	11.08	7.66

It was thought that most of the nitrate of soda was washed away by rains, and that better results might have been got from this material by using it in larger quantity and applying it at intervals as a top-dressing.

Simultaneously with the tabulated experiments, two plots were manured with night soil from city cesspools applied in such quantity that the cost was $14.87 for each of the ⅕ acre plots. There were harvested from these two plots 12.14 and 11.35 bushels of oats respectively. It is noticeable, both as regards the night soil and the guano, that the largest crops were obtained from the manures most likely to be charged with the ferment which would cause nitrification of the moor earth. It will be noticed also that $20 worth of plain guano to the acre gave almost as large a crop (55½ bushels to the acre) as night-soil applied at the rate of $74 worth to the acre.

Humus cools Soils.

The influence of dark-colored substances upon the temperature of the soil has already been insisted upon; and it may possibly be true that humus sometimes tends to make a soil warmer by virtue of its color, but this is not its usual mode of action. On the contrary, it chiefly serves to cool the soil, and it often does good in this way; i. e. by regulating the temperature of the soil, by means of the water which it holds. At mid-day, in summer weather, the surface of a mere sandy soil may become so hot that the hand can hardly be held against it. But if such soil be charged with humus, through abundant dressings of long manure, or by the addition of peat, it cannot readily become so hot by the action of the sun's rays; for the water which the humus sucks up from the subsoil, and absorbs from

the air which rises out of the subsoil will slowly evaporate, and in so doing will consume so much heat that the soil itself will remain comparatively cool.

Fixation of Bases by Humates.

Some reference has already been made to the power of humus to absorb and hold the vapor of ammonia and of carbonate of ammonia, and the subject will again be referred to hereafter. It is to be noticed, moreover, that by virtue of the humic acids contained in it humus can combine with lime and magnesia, and with the bases contained in alkaline substances such as the carbonates and soluble silicates of potash and soda, i. e. humus can absorb and fix and hold these basic substances. The humates of lime and of magnesia, like most other humates, are wellnigh insoluble in water; but potash and soda, when present in excess, form soluble humates. In the soil, however, these basic alkaline humates quickly unite with other humates of metals or earths, and form double salts which are only very difficultly soluble.

Detmer describes a double humate of lime and ammonia as being soluble in rather more than 3,000 parts of water, and one of iron and ammonia as dissolving in 5,000 parts of water, at 66° F. The acid humates of potash and soda, such as would naturally form in any soil rich in humus on the addition of a small quantity of an alkaline carbonate, are wellnigh insoluble in water.

It is noteworthy that some varieties of humus are capable of absorbing a larger quantity of potash, soda, or ammonia from the carbonates of these substances than from the caustic hydrates. Thus Professor Johnson found that a peat from New Haven could absorb 1.3% of ammonia from a solution of carbonate of ammonia, but only 0.95% from a solution of caustic ammonia. Several chemists have noticed, moreover, that soils rich in humus absorb alkalies more forcibly after having been limed, or mixed with carbonate of lime.

The peat examined by Professor Johnson probably contained humate of lime, which, though unacted upon by caustic ammonia, is readily decomposed by carbonate of ammonia, with formation of humate of ammonia and carbonate of lime.

In case a field to be fertilized contains free humic acid, a preliminary liming would neutralize this substance, and by forming humate of lime would prepare the way for the fixation of potash or phosphoric acid and other fertilizing matters, such as would naturally

be applied to the land in manures. It is to be noted, however, that this remark applies more particularly to low-lying soils, and especially to soils that are said to be "sour"; for in good humus, such as exists in garden loam or in almost any really fertile field, the humic acids are not free, but combined with one base or another to form salts of the humic acids, or, as the common saying is, "humates" which are already competent to fix the constituents of fertilizers. Ordinary cultivated soils contain no free acid other than carbonic acid. They are neutral, or even alkaline, to litmus paper.

In ordinary soils the ingredients of humus are so circumstanced that only some traces of them can be dissolved out of the soil by water; but from peat, leaf-mould, and even from rich garden earth which through fermentation or decay has become charged with carbonate of ammonia, water will extract an appreciable amount of soluble matter, which is sometimes in the condition of humate or ulmate of ammonia. There can be no question that these solutions may do good service sometimes, both by reacting upon various matters in the soil and rendering them soluble and available as plant-food, and by being converted into nitrates by fermentation and oxidation.

Humates insoluble in Saline Solutions.

An interesting fact, noticed by Knop, is, that the humates in the soil are much less soluble in saline solutions than they are in pure water. Thus, if a quantity of loam be treated with successive portions of water, the first filtrate will come through almost colorless, while the succeeding portions of the filtrate will be decidedly colored from the presence of dissolved organic matter. That is to say, as soon as the saline matters natural to the soil have been rinsed away by water, certain compounds of humic acids will dissolve in fresh water to an appreciable extent. It would seem, therefore, that a new solvent force must be brought into action in the soil when the conditions are such that solutions of humates can appear; as, for example, after continuous rain.

Solutions of phosphates of the alkali metals, and especially phosphate of ammonia, which dissolve humates, are exceptions to the foregoing rule; and both Schulze and Knop have noticed that the solutions of humates which appear, as above described, on percolating soils with water after they have been washed free from saline matters, contain appreciably larger quantities of phosphoric acid than the first filtrate does. By direct experiment, Knop found,

that, as a rule, the solubility of humates is very much less in solutions of sulphate of potash, or of the nitrates of potash or lime, than it is in mere water.

According to Detmer, humic acid itself is much less soluble in solutions of chloride of potassium, chloride of sodium, and nitrate of potash, than it is in pure water. The mineral acids, i. e. chlorhydric, sulphuric, and dilute nitric acids, dissolve no more than traces of humic acid, though phosphoric acid can dissolve rather more. Detmer determined that one part of humic acid dissolves in 8,333 parts of water at 43° F. and in 3,571 parts at 65°. Dry humate of ammonia, on the contrary, is readily soluble; one part of it dissolves in 2¼ parts of water.

Few, if any, Agricultural Plants feed upon Humus.

Much has been said and written in times past, as to the importance of humus considered as a direct carbonaceous food of plants. But all the evidence goes to show, at least as regards agricultural plants, that neither humus nor any of its components have any practical significance in this direction.

There are plants, it is true, of great interest to the physiologist, which feed upon humus and other decaying vegetable matters, or directly upon dead plants; and it is supposed that both the nitrogen of the humus and the organic matters in it are made available for them by the action of unorganized ferments. But it is known that agricultural plants (excluding mushrooms from the category) can grow perfectly well without any humus. This fact is made evident by experiments which have been made by way of water culture, and by those made with factitious soils. Boussingault's sunflower, for example, grew to perfection in a soil totally destitute of carbonaceous matter, excepting what was contained in the seed from which the plant sprung; and similar results have been obtained by many other observers. Beside laboratory experiments, there is the example of successful agriculture in many sandy countries, where fertility has been obtained, even from the first, by means of irrigation. The first vegetation on the globe must have grown without the aid of humus, even more certainly than is the case with the plants of low orders which are now sometimes to be seen growing upon bare rocks, or of the sea-weeds which are seen growing in the water.

But though humus is not necessary to the growth of plants, and though there is no cause for supposing that it plays any important

part as a direct source of carbonaceous food, it is not altogether improbable that some of the soluble portions of humus may be taken up by plants from the soil. Detmer has found indeed, that, although humic acid and the humates are colloid bodies and non-diffusible, apocrenic acid and its salts, which result from the oxidation of humus, are easily diffusible, and are in fact taken up by pea plants.

Petermann also found, on placing half a dozen loams of different kinds upon parchment paper, the other side of which was kept in contact with water, that not only inorganic matters (viz. lime, magnesia, iron, potash, soda, and sulphuric, chlorhydric, silicic, phosphoric, and nitric acids) passed out from the loam through the paper by way of osmose, but that appreciable quantities of soluble organic matter also diffused out from the loam into the water. He found that quantities of matter ranging from 0.04 to 0.26 grm. passed out from 100 grm. of loam into the water in ten days' time, and that from 0.01 to 0.18 grm. of this matter was organic. In fact, the amounts of organic matter which passed through the membrane varied from 20 to 69% of the total matter which passed through.

Petermann remarks, that this organic matter is neither humic acid, nor humate of ammonia, nor the so-called black matter of Grandeau, all of which substances are colloid and non-diffusible. It recalls rather the neutral soluble organic matter, "analogous to dextrin or sugar," which was extracted from loams long ago by De Saussure, and by Verdeil and Risler.

There was consequently no improbability in the old supposition that organic matters taken into the plant from the soil might serve to nourish it in respect to carbon. It is a matter of experience, however, that the amount of carbonaceous matter thus taken in by the roots of agricultural plants is, under ordinary circumstances, too small to be worth considering; though there are still some exceptional cases, as, for example, that of the smart-weed and other rank-growing plants that flourish on the edges of barnyard pools, where the amount of soluble carbonaceous matter absorbed may possibly be sufficient to exert an appreciable influence on the growth of the plant. But it must always be remembered that it is the nitrogen of the dung liquor that causes the rank growth of the weeds, and attracts attention to them. (Compare "How Crops Feed," pages 232 to 238.)

As a substitute for the old so-called humus theory just alluded

to, it was taught at one time that although humus may not nourish plants directly, or be absorbed and assimilated as such, it is nevertheless extremely useful as a slow and constant source of carbonic acid to be absorbed by the roots. The idea was, that, like leaves, roots could absorb carbonic acid, and that they could extract from the soil the carbonic acid which is generated there by the oxidation of the humus.

But even this supposition is no longer tenable, for it does not appear that much of any carbonic acid is absorbed by the roots of plants, and it is known that considerable quantities of the gas are given off by roots. Moll found, moreover, that starch was not formed in the leaves of plants that were kept in atmospheres free from carbonic acid while carbonic acid was supplied to their roots. Indeed, starch was not even formed in individual leaves kept in atmospheres free from carbonic acid when the other leaves of the plant were abundantly supplied with this gas. Nor was starch formed in parts of leaves that were kept in air free from carbonic acid while the rest of the leaf was supplied with it. No appreciable increase in the rate of formation of starch could be detected in the leaves of plants growing in the open air when carbonic acid was supplied to their roots.

The experiments of Dehérain and Vesque in like manner go to show that no carbonic acid from the soil is taken in by plants to be used by the leaves. These observers were unable to detect any evolution of oxygen from the leaves of plants unless carbonic acid was supplied to the leaves directly from the air. Of course, much carbonic acid, formed by the oxidation of humus in the soil, is continually thrown into the air, as has been already explained, and is there put to profit by the leaves of plants.

CHAPTER XVIII.

DUNG AND URINE. — FARMYARD MANURE.

The value of dung of any kind depends so nearly upon the quality and quantity of the food eaten by the animals from which it drops, that it is difficult to arrive at just conclusions as to the

average chemical composition of any one kind of dung, or to frame precise rules for its preservation and application.

The fertilizing power of dung and urine is due mainly to the nitrogen compounds and to certain inorganic matters, notably phosphoric acid and potash, which are contained in them. Mere dung contains no very large amount of humus-producing materials; though, as ordinarily applied to the land, in the form of farmyard manure, it is usually mixed with much straw or other organic matters which have served as bedding for the animals, or been rejected from their cribs.

It has been found by experiments, that the dried excrements of horses amount on the average to 47.4% of the dry matter of the food they have consumed; i. e. the dry excrement is rather less than half the dry food. So too, as regards cows, the weight of their dried excrements has been determined to be 47.8% of the weight of the dry matter in the food.

As regards the inorganic matters of the food, the whole of them, of course, go into the manure. It is plain enough, at the first glance, that, in so far as the inorganic matters are concerned, a lot of cattle fed upon grain (which is rich in phosphoric acid) will yield manure of far higher value, as regards phosphoric acid, than a similar lot of cattle fed only on the straw from which the grain was threshed. Even if this second lot of cattle were fed upon straw and roots, the value of the manure, as regards the phosphatic constituents, would still be less than that from the grain-fed beasts.

But as regards the nitrogen compounds, which have on the whole a much higher money value than either of the other constituents in the manure, the question is far less simple. Much depends, indeed, upon the quantity of the food eaten, as well as upon its composition and quality. When animals are allowed to eat their fill of rich food which contains much nitrogen, comparatively large quantities of the nitrogenized products of digestion will pass through them, and their manure will be exceptionally rich in nitrogen.

On the other hand, it would be easy to maintain cattle, even in tolerable condition, on such a ration of straw admixed with a little grain or with small additions of roots, that the dung, though rich in inorganic materials, would be exceptionally poor in nitrogen. It might even be possible to substitute pure cellulose (paper-maker's pulp) for the straw in this experiment, and so reduce the proportion of nitrogen in the dung still lower.

But, by feeding heavily with oil-cake, it would be easy to obtain dung rich in nitrogen as well as in ash ingredients. The well-known difference between the dung of stall-fed horses and that of horses at grass is a case in point. Marshall, writing in 1796, says: "Besides his unfair method of feeding (on particular patches of grass), the horse is disliked in pastures, on account of the worthlessness of the dung of horses at grass. This appears somewhat paradoxical when the superior value of their dung in the stable is considered. But the idea is not confined to this district [Yorkshire] nor to England alone; it prevails in America, and more or less in every place where husbandmen observe attentively."

Generally speaking, however, the manure obtained from neat cattle will be found to vary more widely as to its composition than that obtained from horses, since the food of cattle is usually subject to much greater differences than the food of horses. Indeed, it is on this account no easy matter to arrive at just conclusions as to the average composition of the manure of cattle.

Influence of Food on Manure.

Everything goes to show how intimately the question of preparing manure is connected with that of feeding cattle. On every farm there must evidently be some one particular style of feeding, which shall give, all things considered, the best possible economic results for that farm.

In one place it will be good policy to expend the food in such manner that the largest possible proportion of the nitrogen in it shall go to nourish the animals, while in another place, where the conditions and requirements are different, it may be best to have a part of the nitrogen pass through the animals to the credit of the manure, even if it should happen that a part of the food were not digested at all.

It must often happen, that the backwoodsman or newly settled immigrant, no matter where, will be in the predicament first mentioned. Suppose, for example, that at the beginning of winter he finds himself encumbered with several head of cattle in rather poor condition, and that he has but a scanty supply of fodder. He has no means of disposing of these cattle or of buying fodder for them; and they are not in fit condition to salt down.

In this event, there can be no question that he must expend what fodder he has in such wise that the largest possible proportion of the nutrient matters in it, woody fibre included, shall go to

maintain the animals. The aim will be to economize food to the utmost, without thought of the manure. Any rich food, such as English hay or refuse grain, that may be at hand, will be doled out little by little, as an addition to and reinforcement of the coarse swamp hay and "browse," by means of which the appetites of the animals are appeased. But the dung from such a stable would compare very unfavorably with that from a parcel of cattle fatting for market, and consuming as much oil-cake, for example, as they can well be made to eat.

The case of the half-starved cattle here mentioned is by no means an uncommon one. It must occur every few years, and especially after dry summers, in all Northern countries where the winters are long, and where there are many small farmers. It may be seen here in New England not infrequently when young cattle are pulled through the winter on rather inadequate rations of bog-meadow hay, or even upon coarser forage than that, reinforced with as little of better kinds of foods as may suffice to keep the animals alive. It does not follow, in the least, that the practice is an unphilosophical one. On the contrary it is, generally speaking, sensible and praiseworthy in this land of rocky pastures, where not a few farmers can keep in summer many more cattle than they can provide rich food for in winter.

Of course, the poorly fed animals must not be brought too near the starvation point. But this consideration is beside the present question. The point to be urged now is simply, that the dung from the half-fed cattle cannot, by any possibility, be very rich.

To see this argument reduced to its lowest terms, we may turn to a Norwegian custom, by which the peasants of that country actually go so far as to use their supply of hay twice over. Many travellers have noticed the practice. The following description of it is quoted from Mr. Laing's "Residence in Norway," London, 1859, page 272. Under date of February 11, he says:—

"I saw this forenoon a piece of rural management which will scarcely be believed. The stock of this farm is 30 cows and 16 horses. The latter, of course, get no grain. A man came out of the stable with as much horse dung as could be heaped on his spade, and laid it down on the snow. He brought one spadeful after another till the stable was cleaned out, and he placed each spadeful in a little heap by itself. He then let out the cows, which ran to the dung and ate it with great relish. This repast, it seems, was regularly given to them once a day.

"These cows were far from being in a starving condition, or driven by

hunger to this strange diet. They were frolicsome, and their skins clean and glossy. They were not at all 'at the lifting,' as it is called in Scotland when the cattle of a small farmer are, from mere starvation, scarcely able to rise. They would have been reckoned in very fair condition for lean stock, not intended for the market, in any ordinary farm in the North of Scotland. The practice is general on the skirts of the Fjelde, about Roraas, and over all Bergens Amt.

"If by a substitute like this the farmer can save a fourth part of hay that would otherwise be consumed, and can show a stock of cattle in such very fair condition for the month of February, the management may not be so laughable as it appears at first.

"The inferior animals appear to be capable of forming acquired tastes as well as man. If the farmer can avail himself of these, whether produced at first by hunger or imitation, so as to spare other food, he is wise in doing so. He should not wait until the cattle are starving before giving them substitutes for hay or straw."

The bearing of this narrative upon what has been said of the value of dung is manifest. Since most of the waste nitrogen resulting from the consumption of food goes off in the urine anyway, it is evident that the twice digested constituents of the dung will be pretty thoroughly deprived of nitrogen; and since the horses observed by Mr. Laing got nothing but hay in the first place, the final cow-dung can hardly have been very rich, except in inorganic ingredients.

It goes without saying, that such devices as these economies of small proprietors, devoid of capital and unable to procure any foddering materials other than those produced upon their own premises, would hardly be in place upon a great whole-handed farm. But the lesson which they teach is none the less instructive for that.

On the other hand, there are certain districts in Europe, as will be explained more fully under the head of Farms, where cattle are kept less for the milk or flesh they yield than for the sake of the manure that is obtained from them. In the rich farming region about Dresden, in Saxony, for example, the land is kept up to the wheat-producing standard by means of stables of milch cows. The cows are fed largely upon clover and distillery refuse from potatoes, — these crops being grown in rotation with wheat. The wheat receives the manure, and the wheat is sold off the farm. Milk, or some dairy product, is sold also; but it is sold for what it will fetch, and is held to be a secondary consideration, the manure for the wheat being always of paramount importance.

Under these conditions, the farmer's aim is to obtain in the dung and urine of his animals the largest possible quantity of manure of the best possible quality. For him, the dictum that "the richer and the more abundant the food, the better the manure," has a very different meaning from what it has for the Norwegian peasant.

So too in England, it has long been customary to buy fertilizing matters indirectly, i. e. in the form of concentrated fodders, of one kind or another, which are used at the farm to fatten cattle, whose manure is employed to enrich the farm.

Fertilizing Value of Cattle Foods.

As a rule, the farmer both in buying and selling cattle food should take note of the value of the fertilizing matters which are contained in it. For example, there are found in one ton (2,000 lb.) of various foods, the following weights of fertilizing substances: —

	Potash. lb.	Phosp. Acid. lb.	Nitrogen. lb.	Estimated Value.[1] $
English hay . . .	34	8	26	4.53
Red clover hay . .	40	12	42	6.60
Dry corn stover . .	34	8	10	2.93
Wheat straw . . .	10	4	6	1.65
Oat grain	8	11	40	4.91
Indian corn . . .	7	11	32	4.07
Cotton-seed meal .	44	59	140	18.39
Wheat bran . . .	27	58	44	8.52
Malt sprouts . . .	42	25	74	10.64
Mangolds	9	2	4	0.91
Turnips	6	2	3	0.67

Fertilizers carried off in Milk.

From a milk farm a considerable quantity of fertilizing matters will naturally be sent away in the milk; about half a pound of nitrogen, namely, nearly a quarter of a pound of potash, and one fifth of a pound of phosphoric acid in every hundred pounds of the liquid. Hence, in case a cow gives 2,000 quarts, or 4,300 lb. of milk in a year, and the milk be all sold as such, there would be

[1] In estimating the value of these fodders, the pound of potash (K_2O) is assumed to be worth $0.045, the pound of phosphoric acid (P_2O_5) $0.05, and the pound of nitrogen $0.10, which is much too low in certain cases, as in cotton-seed meal, for example, in malt sprouts, and in bran. Perhaps 15 cents the pound for nitrogen would be a fairer estimate, in these three instances. Still, the cost of handling the heavy dung diminishes the value of its constituents, as compared with those contained in concentrated commercial fertilizers. The data which relate to the composition of the fodders are taken from the tables at the end of "How Crops Grow."

carried away from the farm 22 lb. of nitrogen, 11 lb. of potash, and 9 lb. of phosphoric acid.

But since in order to get so large an amount of milk the cow must be richly fed, her manure will be doubly valuable, so that the real loss of fertility to the farm where milk is sold will be less than the foregoing figures would seem to indicate, and less, indeed, than would be the case on many farms where crops are sold directly.

Old Views as to the Relations between Food and Manure.

It is an old rule that the dung and urine of cattle represent the plants upon which the cattle have fed minus those portions of the food which have been abstracted by the acts and processes of nutrition. But it is a rule which must not be taken too literally, in view of the great changes in chemical composition which the components of the plants undergo within the animals.

Young cattle, in growing, do of course subtract from the dung product whatever of phosphoric acid or of nitrogen is laid up within them to form bone, or flesh, or hide, or hair, or gristle. So too in respect to breeding animals, and to those which produce wool or milk. Moreover, it was thought, formerly, that a considerable portion of the nitrogen of the food of all animals is exhaled in the process of respiration, and so lost.

Boussingault found, for example, that some horse manure examined by him (dung and urine together) contained only 83% of the nitrogen consumed in the food. In cow manure he found 87%. But it is now known that the large loss observed by Boussingault must have been due to some error in his method of experimentation. It is not unlikely that his samples of dung and urine may have been allowed to stand long enough to undergo some slight fermentation after they had left the animals and before the analyses were begun. Numerous recent experiments have shown that, practically speaking, and excepting what is stored up in wool, flesh, milk, or the like, all the nitrogen eaten by animals in their food comes out from them again in the urine and dung. Next to none of the nitrogen of the food leaves the animal in the gaseous form. Animals do not exhale either ammonia or free nitrogen, excepting of course the nitrogen of the air, which is breathed in as such and breathed out again.

The Nitrogen in Manure is easily lost.

The ready loss of nitrogenous matters by fermentation of the dung and urine, which doubtless vitiated Boussingault's results, illus-

trates the important practical fact that much of the fertilizing matter in the food never gets back to the land. And the worst of it is, that much of the nitrogen is lost as free nitrogen gas. This question has been studied by several observers. Reiset, for example, found that an abundance of free nitrogen is evolved from decaying horse dung, stable manure, flesh, etc. He noticed that the evolution of nitrogen seemed to be specially pronounced when the dung was suffered to decay under water. But Lawes, Gilbert, and Pugh found that it is when they are in presence of an excess of oxygen that decaying matters are most apt to evolve free nitrogen, and this result has been fully confirmed by Armsby.

Dungs differ as Animals do.

It hardly needs to be explained that what has been said above, concerning the relation of the food to the value of the dung, is strictly true only so long as the food and the dung of any one given kind of animal are compared. Each kind of manure has its own characteristics and peculiarities, in consonance with the fact that each kind of animal has its own way of utilizing and of rejecting food. There are, naturally enough, as wide differences between the excrements of dogs and cows as there are between the structure, kinds of food, and habits of life of the two animals.

In any event, the dung of flesh-eating animals, that of cats, for example, will manifestly be richer in nitrogen, and sometimes in phosphates also, than that of grazing animals. The same reasoning will apply to the mixed feeders, and it is true in fact that the excrements of men and swine and poultry are in fertile regions held to be more valuable than those of the grass-eating animals.

It is noteworthy by the way that the French and German cultivators who are accustomed to pasture swine, or to feed them upon very thin wash of one kind or another, hold hog manure in comparatively small esteem. It is only in England and in this country, where hogs habitually get grain or milk to eat, that their manure is thought to be worth much.

There are some experiments by Christiani which illustrate the value of the manure from fatting hogs. He compared it as to its practical effect with the manure produced by other kinds of stall-fed animals. Each of his experimental plots was heavily manured with the dung that had been allotted to it twice in a seven years' rotation of crops which consisted of winter rape (manured), barley, wheat, oats, barley, wheat, and potatoes (manured). Reducing the

crops harvested to terms of rye, it appears that there were produced in the seven years, from the hog manure, 12,594 lb.; from the horse manure, 12,190 lb.; from the sheep manure, 11,485 lb.; and from the cow manure, 10,887 lb.

I am ignorant whether precise experiments have ever been made from the chemical point of view to test the comparative practical value of the excrements of different kinds of animals, fed, under like conditions, upon one and the same kind of food. It would not be very difficult, for example, to test this point by feeding separate parcels of cats and goats on bread or crackers, or by feeding hounds, sheep, and hens on Indian meal. Some of the older agricultural experimenters may have attempted the thing without recourse to analysis; but without the help of chemistry they must have labored under great disadvantages.

Perhaps the classification of the French agriculturist Dombasle may have been founded on experiments in which the food of the animals was the same. Taking the dungs at their normal condition of dryness, he gives the order of "strength" for similar quantities of the several kinds as follows: goat, sheep, horse, hog, cow.

It would be the more interesting to determine by experiment the composition and quantity of dung from different animals similarly fed, because we are so much in the habit of contrasting the dung of animals that have been differently fed, that our conceptions upon this particular point are apt to be vague.

It is no wonder that the dung of the stall-fed horse is better than that of the grass-fed cow; but how is it when both are grass-fed? As has been said already, the dung of grazing horses is so far inferior to that of grain-fed horses that many people have esteemed it to be wellnigh worthless. But because it is wellnigh worthless as compared with stable manure, it does not follow that it is inferior in any way to cow manure produced under similar conditions. On the contrary, from what is known of the physiology of the horse, it might perhaps be argued, with some show of reason, that, with like rations, horse dung would sometimes be better, chemically speaking, than cow dung.

One reason why the dung of pastured horses may do less good to the land than the dung of cows is, that the droppings of the two animals may ferment in different ways upon the land. Possibly, more nitrogen may go to waste during the decay of the loose dry droppings of the horses than will escape from the more compact

flakes of cow dung. It was remarked withal long ago, by Sir Humphrey Davy, that one reason why horses do not benefit pastures will be found in the fact, that, while they consume the grass by night, they drop a good part of their manure during the day-time, while they are at work upon the roads. The remark was made, it should be remembered, at a time when all transportation in England was by means of wagons on roads or by boats on canals.

Analyses of Manure.

Of the many analyses of manure which have been made hitherto, those of Stoeckhardt may first be cited as giving a good general idea of the differences which subsist between the different kinds of dungs.

In 1,000 pounds of fresh dung of the kinds specified he found the number of pounds of constituents that are stated in the table.

	Sheep fed on 2 lb. Hay per Diem.	Swine, abundant Winter Food.	Horses, Winter Food.	Cows, Winter Food.	Human Fæces (Way).
Water	580	800	760	840	750
Solid matter . . .	420	200	240	160	250
Ashes	60	30	30	24	29
Organic matter . .	360	170	210	136	221
Nitrogen	7½	6	5	3	15
Phosphoric acid . .	6	4½	3½	2½	11
Alkalies	3	5	3	1	4
Lime and magnesia .	15	8	3	4	8
Sulphuric acid . . .	1½	½	½	½	½
Salt	¼	½	trace.	1/10	½
Silica	32	16	20	16	4
Oxide of iron . . .	..	..	..	..	1½

A general view of the composition and value of urine, as compared with that of dung, may be got from the following table, also taken from Stoeckhardt. 1,000 lb. of fresh urine of the kinds specified contain pounds of

	Sheep fed with Hay.	Swine, meagre Diet, chiefly Potatoes.	Horses, Hay and Oats.	Cows, Hay and Potatoes.	Human Urine (Way).
Water	865	975	890	920	970
Solid matter . . .	135	25	110	80	30*
Ashes	36	10	30	20	10
Organic matter . .	99	15	80	60	20
Nitrogen	14	3	12	8	6
Phosphoric acid . .	½	1¼	..	..	½
Alkalies	20	2	15	14	1½
Lime and magnesia .	6	½	8	1½	½
Sulphuric acid . . .	4	½	1½	1½	1/10
Salt	2½	5	2	1	6
Silica	trace.	trace.	¼	1/10	..

* Notwithstanding the large proportion of water in urine, the amount of solid matter in the urine voided by a man in a day is about one third larger than the amount of dry matter in the solid evacuations of a day.

Urine a forcing Manure.

It will be noticed that the comparatively large proportion of nitrogen in the urine of animals corroborates the common view of farmers that urine is a "forcing manure." Fresh urine is, in fact, a very valuable nitrogenous fertilizer. In cases where it can be brought immediately to the crops, each pound of this nitrogen may be rated at as high a price as has to be paid for the pound of nitrogen in guano or in nitrate of soda.

The nitrogen in mere dung is of very inferior quality to that in urine, since most of it is insoluble and in a condition unassimilable by plants. It is contained chiefly in the undigested, not to say indigestible, portions of food which have been expelled by the animal as useless for his purposes, while the nitrogen in urine is all in solution, and in a condition fit to be immediately taken up by plants. Considered from this point of view, the money value of the dry matter in urine is far larger than that in dung, as may readily be seen by computing the value of the constituents in 100 or 1,000 lb. of both, in accordance with the data given on a previous page. With regard to the state in which the nitrogen is contained in fresh manure, something may be learned from the results of experiments made by Boussingault, Von Bibra, Wolff, and Henneberg.

Wolff collected during 2½ days in April all the manure that was produced by a stable that contained 46 cows, 20 heifers, and 14 calves. The animals were fed chiefly on hay and beets. They received 11,810 German lb. of fodder and bedding during the period in question, and produced 14,550 lb. of manure which contained 4,030 lb. of dry matter. A small portion of the fresh manure was taken for analysis, and the rest of it (14,330 lb. of fresh = 3,975 lb. of dry manure) was left out of doors for a year in a heap 3 or 4 feet high. At the end of the year the heap was no more than about one foot high, and its contents weighed 6,730 lb. when moist, and 1,360 lb. when dry. The following percentage of matters was contained in each of the two kinds of manure.

	Dry fresh Manure.		Dry rotted Manure.	
Soluble organic matters	9.7	14.4	7.0	12.0
Soluble mineral matters	4.7		5.0	
Insoluble organic matters	76.3	85.6	56.3	88.0
Insoluble mineral matters	9.3		31.7	
Nitrogen in soluble organic matters	0.63	1.65	0.3	2.1
" in insoluble organic matters	0.86		1.7	
" in NH_3 compounds	0.16		0.1	

No nitrates could be detected either in the fresh or the rotted manure. The loss of soluble nitrogen as the dung decays depends in part on the leaching action of rain, in part on volatilization of ammonia, and in part on the formation of inert humus-like compounds.

Heiden determined how much dung and urine were voided daily in winter and in summer by a stable of 30 head of cattle, as follows.

	Lb. Fresh Manure.			Lb. Dry Substance.		
	Dung.	Urine.	Total	Dung.	Urine.	Total.
Winter	95	9	104	19	0.42	19.42
Summer	88	17	105	17	0.57	17.57
Very salt food . . .	82	36	118	17	0.88	17.88

When the food of the animals was very salt, as in the last line of the table, more water was drunk and more urine voided, but there was no increase in the amount of dry manure. Throughout the experiments, the food was abundant and varied. In winter it was dry for the most part, but in summer much of it was green.

The waste of this manure as it lay in carefully kept dung-heaps and urine cisterns was as follows.

Loss of original Materials in the Course of	From the Manure from Winter Food.		From the Manure from Summer Food.	
	Fresh Manure.	Dry Matter.	Fresh Manure.	Dry Matter.
	%	%	%	%
6 weeks	6.36	16.76	8.03	27.37
9 "	12.80	23.03	15.11	33.19
12 "	18.28	25.42	19.18	35.46
15 "	17.80	26.21	20.40	35.92

It was found in subsequent experiments that this waste could be lessened very considerably by the use of gypsum and kainit (which see). In another trial where the dung was not firmly packed, but merely thrown into loose heaps from hand-barrows, the loss of moist manure in 15½ weeks was 25%, and the loss of dry substance 35%.

Amount of Urea in Urine.

Boussingault found that while the urine of oxen generally contains 8 or 9% of solid constituents, there is from 1.8 to 1.9% of urea. The proportion of hippuric acid varies greatly, Von Bibra says from 0.55 to 1.2%. Some chemists have held that fodder, rich in lignin specially tends to the production of hippuric acid. Henneberg and Stohmann found most hippuric acid (2.1 to 2.7%) in the urine of oxen that were fed with the straw of wheat or oats to which a little bean-meal had been added. With hay alone, they found from 1.2 to 1.4% of hippuric acid. As a rule, the addition of easily digestible foods to the ordinary hay or straw ration diminished the hippuric acid, and increased the proportion of urea. Urea contains nearly half its weight of nitrogen, uric acid about one third of its weight, and hippuric acid less than 8%.

Generally speaking, the proportion of urea in urine is intimately connected with the digestion and utilization of nitrogenized foods. To show how widely the amount of it may vary according to the character of the food, the following table is appended. It relates to human urine, as investigated by Lehmann.

	Solid Constituents.	Urea.	Uric Acid.	Extractive Matters and Salts.
On a mixed diet . . .	67.82	32.50	1.18	12.75
On an animal diet . . .	87.44	53.20	1.48	7.31
On a vegetable diet . .	59.24	22.48	1.02	19.17
On a non-nitrogenized diet	41.63	15.41	0.74	17.13

The figures given thus far refer for the most part to fresh dung and fresh urine. An abstract of Voelcker's elaborate analyses of fresh, half-rotted, and well-rotted manure will be given hereafter. It will be enough to say here that the results of his analysis of well-rotted manure went to show that a dressing of no more than 15 short tons of it to the acre would supply 183 lb. of nitrogen, 135 lb. of phosphoric acid, and 147 lb. of potash, all regarded as "real," so to speak, and not combined with anything. If these ingredients be valued at 10, 6, and 4½ cents the pound respectively, the 15 tons would contain $33 worth of them, and a cord weighing 4 tons would be worth about $8.

Dung Liquor.

Voelcker analyzed dung liquor also, viz. some that had drained out from an old heap, and some that had drained from a fresh heap of manure. He found in a gallon of the liquor the following numbers of grains of the several constituents.

	Old Heap.	New Heap.
Ammonia expelled by boiling	36.25	15.13
Ammonia not expelled by boiling	3.11	
Ulmic and humic acids	125.50	. . .
Carbonic acid expelled by boiling	88.20	. . .
Other organic matters	142.60	711.81
[Nitrogen in these organic matters	3.59	31.08]
Soluble silica	1.50	9.51
Phosphate of lime with a little phosphate of iron	15.81	72.65
Carbonate of lime	34.91	59.65
Carbonate of magnesia	25.66	9.95
Sulphate of lime	4.36	14.27
Chloride of sodium	45.70	107.32
Chloride of potassium	70.50	60.64
Carbonate of potash	170.54	297.38
In the gallon	764.64	1358.81

The liquor from the new heap was almost twice as concentrated as that from the old heap, since, as it happened, the latter had been diluted to a considerable extent with rain-water. The large amount of nitrogen in organic combination found in the liquor from the new heap shows that comparatively little decomposition had occurred there as yet.

Wolff gives the average percentage composition of dung liquor as follows.

Water.	Organic Matter.	Ash Ingred.	Nitrogen.	Potash.	Phosp. Acid.	Lime.	Magnesia.
98.20	0.70	1.10	0.15	0.49	0.01	0.03	0.04

Payen and Boussingault found in Flemish liquid manure 0.19 to 0.22% of nitrogen.

Field Experiments with Dung Liquor.

To test the fertilizing power of barnyard liquor as applied to grass, Wollny divided three grass plots in such wise that the grass was mown for hay on half the area of each plot while the rest was allowed to go to seed. Half the grass and half the seed-hay was manured with barnyard liquor at the rate of 600 gallons to the acre, while the other half received no manure. The results of these experiments are given in the table.

	Grass Plot.		Seed Plot		Total
	Grass.	Hay.	Seeds.	Straw.	Harvest.
French ray-grass (Avena elatior)	lb.	lb.	lb.	lb.	lb.
manured with barnyard liquor .	9,209	2,123	80	2,890	6,830
Same, no manure	5,648	1,690	51	2,304	5,321
English ray-grass (Lolium perenne)					
manured with barnyard liquor .	5,520	1,364	486	1,210	4,692
Same, no manure	1,720	508	172	510	1,698
Festuca pratensis, manured with					
barnyard liquor	6,672	1,669			
Same, no manure	2,240	671			

On analyzing the hay of the French ray-grass, it appeared that the parcel which had been manured was of much better quality than that which had recived no manure, in that it contained a much larger proportion of nitrogenized matters, viz. 9¾% albuminoids against 7½% in the unmanured hay.

Use of Liquid Manures.

There are several countries where liquid manures are esteemed to be superior to all others. In some parts of Switzerland, for example, in Holland, and particularly in Belgium, liquid manure is used freely. Even in recent years Dr. Voelcker has noticed that the

Belgian farmer, as a rule, is anxious to obtain as much liquid manure as possible, and to this end he rather invites than prevents the rains which fall from the unguttered roofs of the farm buildings to find their way to the dung heap.

Not only does he carefully collect in tanks the drainings of dung heaps and liquid refuse from the house, but it is an old custom in that country to prepare liquid manure expressly for certain purposes by mixing dung with water. One plan is to stir oil-cake into the tank which contains the mixture of dung and water, and to leave the mixture to itself during 3 or 4 weeks in order that it may undergo fermentation before it is applied to the land.

This custom is recognized to be advantageous in so far as the liquid condition of the manure permits its even distribution throughout the soil, so that, as is the case with superphosphate of lime, the plant roots may everywhere find a supply of nutriment. But the preparation, preservation, and application of the liquid manure involves the necessity of tolerably costly cisterns and a great deal of labor and oversight, so that, with rare exceptions, the system has hitherto been confined to countries where the processes of agriculture depend on what may be called horticultural methods. In other words, liquid manure is used in a few countries where the land is divided into gardens rather than into farms.

Mr. Secretary Jenkins has argued, with much truth, that "The chief reason why so much trouble is taken by the Flemish farmer to save every particle of liquid, as well as of solid manure, and why so much time and labor are spent in its management, is simply that the small farmer has an excessive dislike to buying anything. Mistaking bulk for quality, his argument is, 'The more manure I can make, the less guano I shall need to buy.'"

But it is none the less true, that the Belgian use of diluted dung liquor teaches a highly important lesson in respect to the mode of action of animal manures, and as to their real superiority over most other fertilizers.

A subordinate point to be noted is, that, for very high farming, liquid manure properly diluted has a certain advantage over guano, in that there is no risk of the crops being "burned" by it, as they might be by guano in case the land were to become dry soon after the application of this fertilizer.

Amount of Manure produced by Animals.

From the experiments of Boussingault, upon a rather small farm horse, and those of Hofmeister, it appears (as Heiden has set forth) that the fresh excrements of a horse fed on hay and oats amount to rather more than 30 lb. a day, and contain some 6 or 8 lb. of dry matter. According as the animal is or is not bedded with 6 lb. of straw, there will be contained in the manure of a single day 0.2 and 0.22 lb. of nitrogen, and 1 lb. and 1.4 lb. of ash ingredients. Very similar figures have been obtained in experiments with cows. Thus, Boussingault fed a cow on potatoes and rowen, and got per diem 73½ lb. of moist excrements that contained nearly 10 lb. of dry matter. According as she was not bedded at all, or with 6 and 10 lb. of straw respectively, it appeared that the manure contained 0.26, 0.28, and 0.29 lb. of nitrogen, and 1.73, 2.05, and 2.28 lb. of ash ingredients.

Henneberg and Stohmann's oxen, that were merely "maintained" at rest, gave for every 1,000 lb. of live weight 64½ lb. of moist excrement that contained a little more than 8 lb. of dry matter. The manure contained 0.22, 0.23, and 0.25 lb. of nitrogen, and 1.3, 1.6, and 1.8 lb. of ashes, according as the animals received no bedding, or 6 and 10 lb. of straw. Fatting oxen gave per 1,000 lb. live weight 82 lb. of moist excrement (or 9 lb. dry), and the manure contained 0.36, 0.38, and 0.39 lb. nitrogen, and 1.8, 2.1, and 2.4 lb. of ash ingredients, according as there was no litter, or 6 or 10 lb. of it.

Analyses of Manures.

The following tables contain the essential points of several other analyses of manures, as determined by different observers.

Cow Manure.

I. Fresh cow manure from animals fed on as much hay as they would eat, with daily additions of 4 quarts of wheat bran, and 4 quarts of mangolds. A cubic foot of this manure weighed 63 lb. (S. W. Johnson.)

II. and III. Taken in February from the centre of dung-heaps at two different cow stables in Germany. (Schmid.)

IV. Four-weeks-old manure from a cow stable where the fodder consisted of a mixture of 100 lb. of green-cut clover, and 5 lb. of rye straw. (R. Hoffmann.)

V. Cow manure. (Bretschneider.)

VI. Average composition of fresh cow manure, with litter. (Wolff.)

VII. *a.* Solid cow dung. *b.* Cow's urine. *c.* Mixed dung and urine. (Payen and Boussingault.)

VIII. Cow manure, winter food? (R. F. Kedzie in laboratory of the Bussey Institution.)

Cow Manure.

	I.	II.	III.	IV.	V.	VI.	VII. a.	VII. b.	VII. c.	VIII.
Water	85.30	77.71	74.02	72.87	75.00	77.50	85.90	88.30	84.30	76.19
Dry matter	14.70	22.30	25.98	27.13	25.00	22.50	14.10	11.70	15.70	23.81
Ash ingredients	2.04	4.71	3.94	6.70	6.22	2.20	...	...	...	3.09
Potash	0.36	0.46	0.56	1.69	0.39	0.40	...	...	...	0.60
Lime	0.29	0.37	0.58	0.41	0.24	0.31	...	...	...	0.58
Magnesia	0.19	0.11	0.13		0.18	0.11	...	...	...	0.08
Phosphoric acid	0.16	0.13	0.07	0.20	0.14	0.16	...	...	...	0.53
Ammonia	0.06	0.16	0.07	...	0.27	...	...	...	...	...
Total nitrogen	0.38	0.54	0.41	0.79	0.46	0.34	0.32	0.44	0.41	0.79

Horse Manure.

IX. Fresh horse manure from stables in New York City. The material contained no long straw, and weighed 35 lb. to the cubic foot, i. e. 4,535 lb. to the cord. (S. W. Johnson, Conn. Agric. Rep., 1873, p. 348.)

X. Sample from a cargo of horse manure from New York City. (S. W. Johnson, Rep. Conn. Agric. Exp. Station, 1880, p. 43.)

XI. Fresh horse dung collected from an animal fed daily on 14 lb. of timothy hay and 4 quarts of oats mixed with cracked corn. The dung was collected in dry winter weather, a few hours after it had been dropped. A sample of fresh dung was found to contain 73.86% of water. (R. F. Kedzie in laboratory of the Bussey Institution.)

XII. Horse manure. (Bretschneider.)

XIII. Average composition of fresh horse manure with litter. (Wolff.)

XIV. *a.* Solid horse dung. *b.* Horse urine. *c.* Mixed dung and urine. (Payen and Boussingault.)

Horse Manure.

	IX.	X.	XI.	XII.	XIII.	XIV. a.	XIV. b.	XIV. c.
Water	75.76	69.30	67.28	72.13	71.30	75.30	79.10	75.40
Dry matter	24.24	24.82	32.72	27.87	28.70	24.70	20.90	24.60
Ash ingredients	5.07	5.05	6.49	3.37	3.30	...	...	...
Potash	0.51	0.63	0.22	0.59	0.53	...	...	...
Lime	0.30	0.74	0.17	0.41	0.21	...	...	...
Magnesia	0.19	0.29	0.20	0.17	0.14	...	...	...
Phosphoric acid	0.41	0.67	0.35	0.12	0.28	...	...	...
Ammonia	0.26	0.12	0.15	0.44	...	...	...	...
Total nitrogen	0.53	0.69	0.47	0.67	0.58	0.55	2.61	0.74

Sheep and Swine.

XV. Sheep manure. (Bretschneider.)

XVI. Average composition of fresh sheep manure with litter. (Wolff.)

XVII. Average composition of fresh hog manure with litter. (Wolff.)

	Sheep. XV.	Sheep. XVI.	Swine. XVII.
Water	69.30	64.60	72.40
Dry matter	30.70	35.40	27.60
Ash ingredients	6.69	3.60	2.60
Potash	0.77	0.67	0.60
Lime	0.60	0.33	0.08
Magnesia	0.06	0.18	0.09
Phosphoric acid	0.21	0.23	0.19
Ammonia	0.45	...	...
Total nitrogen	0.61	0.83	0.45

Payen and Boussingault found 81.40% of water and 0.63% of nitrogen in hog manure, 63% of water and 1.11% of nitrogen in sheep manure, and 46% of water and 2.16% of nitrogen in goat manure.

Mixed Farm Manure.

XVIII. Half-rotted stable manure from horses, neat cattle, and swine. (Boussingault.)

XIX. Well-rotted barnyard manure from young neat cattle fed with hay. The manure contained a good deal of clay — more than one quarter of its weight — from the barnyard. One cubic foot of the mixture weighed 40 lb. (S. W. Johnson.)

XX. Average composition of fresh farm manure. (Wolff.)

XXI. Average composition of moderately rotted farm manure. (Wolff.)

XXII. Average composition of very thoroughly rotted farm manure. (Wolff.)

XXIII. Mixed cow and horse manure from a bed two feet thick, which had accumulated during the winter in a large covered yard. The bed of manure was packed solid by the tramping of cattle upon it. It was estimated that 80 tons of straw had been used for bedding 45 animals 195 days, and that 466 tons of manure were produced. (Roberts, 3d Cornell Report. The analysis by F. E. Furry.)

XXIV. Similar to No. XXIII., but produced during another year, when less cotton-seed meal was fed. In this case, 24 cows, 1 bull, 12 horses, 1 colt, 7 winter calves, and 12 spring calves, regarded as 47 adult animals, produced 199½ tons of manure in 5 months, — October 1 to March 2. (Roberts. The analysis by a student named Breed.)

XXV. "Box manure," consisting of the mixed manure of bullocks, horses, and pigs. On separating dung from straw, by means of a fine sieve, there was found 58.3% of dung, and 41.7% of straw. (Way, Royal Agric. Soc. Journ., 1850, II. 769.)

Voelcker's elaborate analyses of fresh and rotted farmyard manure will be given on a subsequent page.

Mixed Farm Manure.

	XVIII.	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.	XXV.
Water	79.62	54.70	71.00	75.00	79.00	79.95	75.57	72.83
Dry matter	20.38	45.30	29.00	25.00	21.00	20.05	24.43	27.67
Ash ingredients	6.56	34.43	4.40	5.80	6.50	...	...	5.87
Potash	0.51[1]	0.16	0.52	0.63	0.50	0.84 (!)	0.70	0.69
Lime	0.56	0.47	0.57	0.70	0.88	...	...	0.85
Magnesia	0.24	0.50	0.14	0.18	0.18	...	...	0.14
Phosphoric acid	0.20	0.72	0.21	0.26	0.30	0.40	0.29	0.30
Ammonia	...	0.01	...	...	...	...	...	0.02
Total nitrogen	0.41	0.46	0.45	0.50	0.58	0.78	0.68	0.46

Number of Cords of Manure to the Acre.

The statements of practical men vary not a little as to the quantity of manure to be applied to an acre of land. New England farmers commonly regard 8 or 10 cords to the acre as an adequate dressing for field purposes, and they probably rarely use more than 12 cords or less than 6. Market gardeners, however, in the vicin-

[1] And soda.

ity of Boston apply horse-manure from the city stables at the rate of 20, 30, 40, or it may even be 60 cords to the acre, — to celery, for example; though some of them are said to now use manure at the rate of 10 or 12 cords, together with 1,000 lb. of guano, or 2,000 of bone-meal, whereby, as is claimed, a great saving in the first cost of fertilization is effected.

In case the soil is rich enough and moist enough to be worthy of heavy dressings of manure, there will be a manifest advantage in applying a considerable quantity of it all at once, because of the economy of labor. The land will need very much the same amount of ploughing, harrowing, and cultivating for a given course of crops, no matter how much manure has been put upon it. Cow manure may be estimated to weigh from 3½ to 5 tons to the cord, say 4 tons on the average. Horse manure, as hauled from stables in the city, weighs some 2½ tons, or perhaps 3 tons, to the cord.

The famous old German writer, Thaer, regarded 17 or 18 tons to the acre as an abundant dressing; 14 tons he called good, and 8 or 9 tons light. Other German authorities speak of 7 to 10 tons as light, 12 to 18 tons as usual, 20 or more tons as heavy, and 30 tons as a very heavy application.

Relation between the Constituents of Manure applied and Crops removed.

If the argument were, that manure should be applied in quantities sufficient to give to the land as much potash and phosphoric acid as the crops carried off, the amount to be used could be ascertained by simply weighing and analyzing both the crops and the manure, and contrasting the results of the analyses. Heiden has made such a comparison for a farm at Waldau, and has obtained the results which here follow. In the course of ten years the crops grown in the rotation practised at Waldau carry off from each Morgen (= 0.631 acre) of land 263 German pounds of potash, 121 lb. of phosphoric acid, and 329 lb. of nitrogen.

But Voelcker found in 100 lb. of fresh farmyard manure 0.672 lb. of potash, 0.315 lb. of phosphoric acid, and 0.643 lb. of nitrogen; while in 100 lb. of well-rotted manure, six months old, he found 0.491 lb. of potash, 0.449 lb. of phosphoric acid, and 0.606 lb. of nitrogen. Hence, to supply the potash of the Waldau crops, some 20 or 25 tons of manure would be needed; — to supply the phosphoric acid, from 13 to 19 tons; and to supply the nitrogen, 26 or 27 tons.

Practically, it was customary at Waldau to apply 25 tons of manure to the Morgen of land in the course of the ten years, in 2½ instalments, so that the land was continually made richer, both as regards potash and phosphoric acid, while in respect to nitrogen about as much was put back upon the land as was taken off.

Here, manifestly, is an instance of the old custom of using enough stable manure to supply the crops with the nitrogen they need, as well as with ash ingredients, and the figures just given well illustrate the unreasonableness of pushing this practice to such an extreme.

It will be noticed, that no account is here taken of the natural waste of nitrogen from land that is under tillage. But it is now known that, while the potash and the phosphoric acid in manures are fixed in the earth by combining with silicates, humates, and oxides which they find there, the nitrogen is not thus held, but tends to waste away slowly by being converted to nitrates, which are leached out by rain and carried off in the drain-water.

Preservation of Manure.

The questions are now fairly in order, What does chemistry teach as to the best means of preserving animal excrements, and of applying them to the soil? These questions, it will be noticed, include a multitude of other questions which have been much disputed; such as, —

Should manure be ploughed in long or short? that is to say, should it be applied fresh or after fermentation?

Should manure be kept moist or dry? housed, or out in the air? in heaps, or in pits? firmly trodden, or loose?

Should it be composted, or kept by itself?

Should it be spread upon land as a top-dressing, or be ploughed in?

And if it be ploughed in, how deep should it be buried?

And so on.

The question of preserving manure is not a little complicated by the fact that each kind of dung ferments in its own special way, so that a method which might be peculiarly well adapted for preserving one kind of manure need not necessarily be suited for preserving another kind.

To take an extreme case, for the sake of enforcing this point, it may be said that fresh human excrements are doubtless more valuable as a manure upon fertile soils than any other kind of dung; but it is exceedingly difficult to preserve them. The night-soil of

cities is in no sense comparable as a manure with fresh excrements, and the various poudrettes, ta-feus, and other products prepared from night-soil, are comparatively speaking worthless; that is to say, very much better and more powerful manures can readily be bought nowadays for much less money.

The trouble is, that the nitrogenized constituents of human excrements are of such character that they begin to ferment, putrefy, and spoil rather more rapidly than so much flesh would; and it happens that during this process of fermentation the best part of the manure goes off in the form of gas.

Earth as a Preservative.

The thought lies near at hand that the excessive power, so to say, of dung so strong as that just mentioned needs to be controlled. Hence the idea, that, if the dung were weakened or diluted by mixing it with inert matters, or with those that are less putrescible than itself, the tendency towards destruction might be diminished.

Undoubtedly this notion contains something of value, but it is subject to many limitations, and has been not infrequently misunderstood. For example, it was thought formerly that the loss of gases was practically merely a loss of ammonia, and it was customary at one time to urge, that, if the excrement could but be mixed at once with earth or peat, most of the gaseous matter would be retained and the manure be preserved from harm.

Of late years, however, chemists are much less emphatic upon this point. They are much less certain than their predecessors were that the evolved gases can be saved, or that they are worth saving if it were possible to save them. It is now known that, beside the ammonia about which so much used to be said and written, there is formed a great deal of worthless nitrogen gas during the process of fermentation. It is known, too, that one quick way of dissipating flesh is to bury it in a layer of charcoal or dry earth to which air has access; and it is but natural to suppose that dung rich in the constituents of flesh will behave something like flesh when exposed to similar conditions. Upon this point more will need to be said under the head of Composts.

Preservation by Drying.

Theoretically, perhaps, the most effective way of preserving human excrements would be to dry them rapidly, and to pack the compressed residue in tight, dry parcels, together with a little salt or

other preservative; and a precisely similar remark would apply to other kinds of dung, though to few of them so strongly.

According to the analysis of Way, the solid part of human excrement would contain when thus dried some 6% of nitrogen, 4½% of phosphoric acid, and rather more than 1% of potash; that is to say, two tons of the dry material would be worth about as much as one ton of good Peruvian guano.

Dried human urine would contain some 19½% of nitrogen, 4½% of phosphoric acid, and 5% of potash.

But this supposed method of preservation is impossible under the conditions of labor and climate in which we live. As things are now, it costs very much less to import guano and potash, or to make superphosphate, than it would cost to dry the manure.

Drying being out of the question, some other method of preventing or of hindering fermentation must be looked for; but it is hard to say which method, among those that are possible, would theoretically be the best; for the problem, as regards manures, is complex to the last degree, and it has never been worked out scientifically. Neither chemists nor mycologists have yet arrived at a knowledge of definite fixed principles upon which to base practical action.

Preservation by Compression in Pits.

In all human probability, however, some system of what may fairly enough be called ensilaging the dung would come nearest to perfection; that is to say, some method of compressing the fresh manure in pits, and covering it up with weighted boards or with earth in such wise that air could not gain access to it. Practically this thing is done not infrequently — in a very crude and incomplete way, indeed — as regards cow dung which is kept undisturbed in barn cellars in cold weather; for the portions of dung first thrown into the cellar are so covered and compressed by the dung which is subsequently thrown upon them that some parts of the heap are often found to be in tolerably fresh condition long after the dung was voided.

Hot Fermentation and Leaching are Bad.

Of course every farmer knows, though not a few of them act as if they did not, that mere dung and urine should neither be allowed to become heated unduly nor to be leached by rain. Even heaps of dung that is admixed with straw or other litter, if exposed to hot summer sunshine, would be liable to be heated and dried improp-

erly, and to suffer fermentations such as might cause great loss of the nitrogenous constituents of the manure. Many persons have urged that, in order to hinder this excessive action, it is well to keep dung in shady places. In the North of France rows of elms are often planted expressly to shade the dung heaps.

But besides the sun's heat in summer there is the leaching action of rain to be guarded against throughout the year. In New England, this country of heavy showers and costly straw, it might well be asked whether some kinds of manure should not in general be carefully protected from rain. There have been those among us who claimed that manure should be thus protected almost as carefully as if it were hay.

Dung Sheds and Cellars.

At one time or another some good farmers, in order to avoid the effects of sun and rain, have had rough sheds built on purpose to shield their heaps of manure. It is not a little doubtful whether such sheds can ever have repaid the cost of erecting them, but the idea of having dung sheds is instructive, since whatever advantages such sheds may possess must plainly be shared by the barn cellars in which manure is very commonly kept in New England. In these cellars the manure is protected from rain, and sun, and frost, and wind, at the same time that it is kept moderately moist and in a condition of slow and equable decomposition. Generally speaking, the manure is subjected also to a considerable amount of admixture and compression by means of hogs that are allowed to run upon it. In a mere shed, it would manifestly be much less easy to keep the dung in such excellent condition, or to prevent it from drying out unduly in hot or windy weather.

There is one objection to the alternate wetting and drying of manure that would count against the use of airy sheds, while it would be avoided in cellars; viz. that noteworthy quantities of carbonate of ammonia may be carried off by the vapor of water as it evaporates from a manure heap or from a barnyard pool. In experimenting upon manures, whether comparatively fresh or rotted, for the purpose of determining how much moisture is contained in them, chemists have repeatedly observed that in the act of drying the dung great losses of ammonia occur. The ammonium carbonate is lifted as it were and carried off by the aqueous vapor.

Something might here be said, however, in favor of the old New England winter practice of allowing the heaps of dung outside the

barns to freeze into solid, stone-like masses. Such freezing would be an excellent means of preservation were it not for the exposure to the spring rains to which these frozen heaps of manure were almost always subjected.

The keeping of swine upon stable manure "to work it over," as the saying goes, is really a point of no small importance, both for the preservation of the chemical constituents of the dung and urine, and for improving the mechanical condition of the manure. The rooting of the swine is an effective means both of mixing the hot horse manure with the cold cow manure, to the manifest advantage of each, and of commingling them with whatever of straw, or leaves, or weeds, or peat, may have been used either as bedding, or have been added directly to the manure for purposes of absorption or of composting. The product obtained in this way is particularly easy of application to the fields, for it admits of even distribution and of being thoroughly mixed with the soil.

Litter may preserve Manure.

Several of the methods of preserving manure which are actually employed by farmers commend themselves from the chemical point of view. Thus the method in ordinary use in Massachusetts, when cows are kept in stall during the winter, of using as bedding enough straw, or leaves, or dry peat, to absorb and hold the urine that comes from the cattle, and keeping the product stored in cool cellars, as has been said.

The old German writer Block was strongly in favor of using mixtures of straw and loam for bedding neat cattle, as a means of improving their manure. He urged that, by means of alternate layers of straw or other litter and earth added fresh every day to avoid balling and impaction, the dung and urine may be absorbed and preserved most completely, i. e. with the least amount of loss.

Several other practical men have maintained that the addition of half a cubic foot of loam per head and day to the straw is advantageous. So too, the use of loam to supplement straw has not infrequently been regarded as a resource in cases where not enough straw could be procured for properly bedding the animals. Thus, when no more than 3 or 4 lb. of straw per head and day can be provided, the deficiency may be made good with $1\frac{1}{4}$ to $1\frac{1}{2}$ cubic feet of earth. Similar quantities of loam have been used also, together with 6 or 8 lb. of straw, in cases where the food of the animals happened to

be specially watery, even on farms where straw was to be had in tolerable abundance.

In general, it may be said that the question of absorbing urine is far from simple in all cases where animals are fed upon watery foods, as when cows are kept up in summer upon mown clover or corn sprouts, and other juicy green foods, or where they are fed in winter on ensilage, or where, as happens in many parts of Europe, they are fed upon the liquid wash from potato distilleries, or upon turnips or beet pulp.

For the sake of thoroughly absorbing the liquid manure, and for convenience also, several European writers have recommended that straw should be cut to foot lengths before using it for bedding animals. The point is one of some interest, as tending to enforce the merit of leaves for this purpose. One method of using cut straw has been described as follows.

The animals are bedded, at the rate of 7 lb. per head and per day, with straw chopped into pieces 2 or 3 inches long. Behind the animals is a trough 9 inches deep and 16 inches wide, which receives the excrements and the bedding of 24 hours. Once a day the contents of this trough are thrown out, and the dung and litter are scraped from beneath the animals and trodden into the trough, there to absorb the urine of the next day. It is said that, even when the animals are fed with distillery slop, none of the liquid excrement escapes absorption.

Manure thus prepared is remarkably homogeneous, and so evenly saturated with moisture that it packs itself firmly in the dung-heap, and "keeps" admirably. On inspecting such a heap at the end of 5 months (June to December), it appeared that decomposition had hardly begun. Such manure is naturally "short," and easy to handle. It can be hauled out and worked into the land at any moment, without need of ever being forked over.

Commonly, however, when cows are fed with watery foods, so much liquid excrement is produced that special pits or cisterns have to be provided, from which the excess of liquid may be pumped up from time to time to drench the solid matter, or to be carted into the fields for use as liquid manure.

Wet Fermentation of Manure.

Manure thus drenched with liquid, especially if it be kept in large heaps or in deep pits, appears to ferment in a somewhat different way from that which is less thoroughly moistened. It becomes

very dark-colored, or even black, and acquires a highly offensive odor, while the straw in it loses its consistency and becomes soft and incoherent. Sulphuretted hydrogen, sulphides, and doubtless other products of reduction, are formed in such manure through the decay of the organic matters, much as they are formed beneath the surface soil of a stagnant marsh; and it is plain that the fermentation is not of a kind either to cause ammonia to be evolved or nitrates to be formed.

This putrid manure is undoubtedly of excellent quality. Such manure is highly esteemed on the continent of Europe, where it has long been customary to prepare it; and so good an observer as Boussingault has said of it, that he could tell by the odor of the sulphides which it emits when farm manure had been properly prepared. In his opinion, these products of reduction can do no harm to vegetation, because they change rapidly to sulphates as soon as the manure has been spread upon the land. But an observer in Holstein has recently insisted that substances injurious to plants do exist in the putrid manure from deep pits, and he urges that it should on this account be spread and left to lie upon the land for a week or two before the time of sowing or planting.

As regards the liquid which collects in the cisterns above mentioned, it is notorious that the quality of it is apt to deteriorate rapidly in these receptacles; and it is plain why it should do so, for the nitrogenous components of urine, viz. urea, uric acid, and hippuric acid, are precisely those constituents of animal secretions which decompose the first and the easiest. The nitrogenous matters in dung proper are far less prone to decomposition.

These cisterns, it may be said in passing, are hardly to be commended for our American conditions. In general, it would probably cost more to erect, maintain, and use them than the gain from them would be worth.

Amount of Litter needed.

Practical men vary widely as to the amount of bedding required daily by neat cattle. The old German authorities speak of 8, 9, and 10 lb. of straw for each cow or ox, and few of them recommend so little as 5 lb. in summer and 7 lb. in winter. Heiden has urged that the amount of litter should vary accordingly as the food is more or less watery; and he suggests that in general an amount of litter equal to one third the weight of the dry matter in the fodder actually eaten will be sufficient.

Absorptive Power of Straw, etc.

Some experiments may here be cited which were made by Heiden to determine the power of straw to absorb and hold water. Small compact bundles of the straws were sunk in water so as to be completely covered. After the lapse of 24 hours, they were taken from the water and set standing in an upright position for half an hour, and they were afterwards left lying for an hour and a half, in order that the excess of water might drain off from them. They were then weighed, and again at intervals, after time had been allowed for some of the water to evaporate. The results of these trials are given in the table.

	Wheat Straw. %	Rye Straw. %	Oat Straw. %	Pea Straw. %
Water absorbed in 24 hours . .	225.8	241.4	213.6	280.9
Water evaporated from the wet straw				
In 2 hours	12.6	11.0	5.0	8.4
Next 2 "	5.8	3.6	4.3	12.7
" 16 "	18.9	35.4	14.5	32.3
" 4 "	6.3	2.2	3.8	8.7
" 4 "	1.1	3.3	2.9	7.5
" 16 "	10.5	12.2	9.5	22.6
In the 44 hours	55.0	67.7	40.0	92.2
Water retained after 44 hours .	170.8	173.7	173.6	188.7

Another bundle of wheat straw, on being left to soak for 48 hours, instead of 24, took up nearly 22% more water. In the 48 hours, that is, it absorbed 247.6%, of which amount 18.7% were given off during the first 6 hours, and 28% during the next 18 hours, or 46.7% in 24 hours; so that 200.9% of water was still retained by the straw even after 24 hours' exposure to the air.

Breitenlohner also has experimented, though much less carefully than Heiden, to test the absorptive power of different kinds of litter. He left the materials to soak for a week with a given weight of dung liquor. The straws were cut into short lengths, and so were the evergreen boughs and the heath litter. The leaf rakings were dry enough to be somewhat crumbly, and the peats were reduced to coarse powder. Most of the materials were more or less air-dried. The results of these trials are given in the table on the next page.

	Moisture in the Litter expelled at 212°. %	1,000 lb. of the Litter absorbs Pounds of Dung Liquor.	Wt. of Liquor absorbed, if that taken by the Fir Twigs = 100.
Rye straw	8.0	3,000	1,200
Straw of horse-beans	10.3	3,300	1,320
Sawdust	6.6	3,571	1,428
Heath litter (including moss)	5.7	3,083	1,233
Leaf rakings	5.1	4,330	1,732
Spent tan bark	5.6	2,150	860
Fir twigs	61.2	250	100
Spruce twigs	54.2	357	143
Peat	10.5	4,483	1,793
Moor earth	4.9	550	220

It will be noticed that, weight for weight, the peat and the wood rakings absorbed more liquor than any of the other kinds of litter, and that sawdust stands near them, while rye straw is somewhat inferior, and the evergreen twigs are least absorptive of all.

It was observed in special trials, that the moor earth in particular, and the peat to some extent, "fixed" a part of the soluble constituents of the dung liquor in such wise that those portions of liquid which were not taken up were found to be weaker than the original liquor; whereas the excess of liquor that drained away from the straws, etc. contained a larger amount of matters in solution than the original liquor had contained.

Fleischer found, on comparing immature peats, consisting on the one hand of the fibrous remains of reeds, and on the other of partially decomposed mosses, that 1,000 parts of either of them (containing already 20% of moisture) absorbed from 6,300 to 9,300 parts of water, and from 13 to 17 parts of ammonium carbonate. But the fibrous peats from reeds were more valuable than those from moss, since 1,000 parts of the dry material contained from 22 to 29 parts of nitrogen and from 17 to 31 parts of lime, while 1,000 parts of the mossy peat contained no more than 9 parts of nitrogen and 2 parts of lime. Both kinds contained about half a pound of phosphoric acid in 1,000 lb. of the dry peat.

Relation of Litter to Food.

It will be noticed that the practical rules given on previous pages apply primarily to grain-growing countries, where straw is abundant and the conversion of it to manure a desideratum. In New England, on the contrary, it might often be well to use the least possible quantity of bedding, or even none at all in some instances.

For bedding horses, German writers hold that from 4 to 6 lb. of

straw are needed daily, and there can be little question that in this case the comfort of the animals is the point first to be considered; though Heiden has argued even for horses that the chief purpose of the bedding is completely to absorb the liquid portions of the excrement. Starting from this assumption, he urges that the true way of determining how much bedding to use will be to consider the character of the food, and so employ more or less straw according as the food is more or less watery. In the case of horses, he thinks no great error will be made if the amount of straw used for bedding is equal to $\frac{1}{4}$ the weight of the food taken in its natural condition, or equal to $\frac{1}{3}$ the weight of the dry matter of the fodder.

It is more important for horses, however, than for most other animals, that they should be abundantly bedded by night in order that they may rest comfortably; and that their stalls should be cleaned out thoroughly and often, care being taken to remove as completely as may be possible the urine and the straw moist with urine. It is important both to avoid the fumes of ammonia that are generated by the putrefaction of urine, and to hold in check the multiplication of various microscopic organisms, hurtful to the hoofs of the animals, which are apt to thrive in putrid litter.

Practical Methods of preserving Manure.

The following rules for preserving farmyard manure, as stated by a French writer, manifestly commend themselves. The dung-heap should be shielded from sun and rain. The fermentation of the heap should be moderated by means of admixtures of loam or some similar material. The heap should be kept moderately moist. Fresh dung should not be mixed with old.

So far as the mere preservation of the manure is concerned, it would be hard to improve upon the practice of certain grain-growing countries, such, for example, as Upper Lusatia, one of the provinces of Saxony, and of some parts of Belgium also, where the dung and litter are allowed to accumulate in thick layers in the stalls, directly beneath the cattle and in contact with their bodies. The animals are bedded heavily with straw two or three times a day, and the mixture of straw and dung beneath them is pushed forward and made level as often as may be necessary for their comfort. The feeding troughs are made to slip on the stanchions, and they are elevated as often as may be requisite. The mixture of dung and straw becomes very firmly compacted by the weight of the cattle,

and, in the rather cool countries where the system is practised, the dung is maintained in a highly favorable condition of moisture.

The small amount of air that can gain access to the interior of the mass, and the even temperature maintained there, seem to be favorable to the proper fermentation of the manure. At all events, it has been thoroughly proved that such manure is more powerful than that thrown out and left to ferment in heaps in the ordinary way. The method is highly esteemed in the places where it is practised, which are, for that matter, some of the finest farming regions in the world. It is no uncommon thing to see a stable so arranged that the impacted manure may come to be 4 feet or more high, — even 7 feet have been noticed, — and extremely hard and firmly compressed before there is any need of bringing in the carts to remove it. It is carried directly to the fields, where it is spread immediately, and ploughed under in due course.

Several cow stables thus arranged which I have myself visited had no unpleasant odor, and it is maintained by the people who practise this method that the health of their cattle does not suffer. It is hard to understand, however, how the hoofs of the animals can always escape the diseases that are apt to be caused by certain microdemes which appear to harbor in fermenting dung, and no man can tell without trial how well the system would answer for dairy farms in this country, i. e. in the warmer parts of it. Doubtless it would serve well enough, however, in the case of fatting cattle.

The practice now in question is a very old one. It applies to the preservation of moist cow dung and the urine of cows. It provides for the thorough absorption of the urine by straw, for the complete admixing of straw and dung, and for the slow, regular fermentation of this mixture. Meanwhile, all the manure is housed and completely protected from the weather. In general, it may be said that the process strongly enforces the advantages to be gained by allowing stable manure to ferment slowly.

The following analyses by Biernatzki relate to the manure of four Flemish farms similarly conducted, with the exception that at Nos. I. and II. the manure was thrown out every day from the cow stalls, while at Nos. III. and IV. the stalls were provided with movable cribs, and the dung was left lying beneath the animals. One hundred pounds of the manure contained, —

	I. lb.	II. lb.	III. lb.	IV. lb.
Organic matter	11.78	13.56	18.16	18.35
Water	83.78	81.42	76.54	75.87
Nitrogen in organic compounds	0.33	0.35	0.48	0.33
Nitrogen in ammonia	0.13	0.11	0.19	0.26
Phosphoric acid	0.26	0.27	0.31	0.33
Potash	0.43	0.74	0.79	0.71

Emmerling, on the other hand, subjected samples of manure from a deep stall and from a dung-heap to elutriation with water in such manner that each of the samples was divided into three portions, viz. into matters soluble in water, fine insoluble matter, and strawy matter. His results are given in the following table. One thousand pounds of the fresh manure contained:

	Strawy Matters.	Fine Insoluble.	Soluble in Water.	Total.
From the Deep Stall.				
Dry matter	148	60	20	228
Ashes	6	11	10	27
Phosphoric acid	0.37	0.91	0.14	1.42
Potash	0.08	0.90	4.69	5.67
Nitrogen in organic matters	0.88	0.67	1.90	3.45
Nitrogen in ammonia	...	...	0.66	0.66
Total nitrogen	...	...	...	4.11
From the Dung-heap.				
Dry matter	115	52	18	185
Ashes	6	11	8	25
Phosphoric acid	0.42	0.52	0.44	1.38
Potash	0.13	0.50	4.11	4.74
Nitrogen in organic matters	0.70	0.99	1.18	2.87
Nitrogen in ammonia	...	...	0.29	0.29
Total nitrogen	...	...	...	3.16

The straw in the manure from the deep stall appears to have been less completely decomposed than that in the dung-heap, a result which points to the similarity of such dung to ensilage. No nitrates could be detected. But it is noticeable, not only that there is more nitrogen in the manure from the deep stall, but that this manure contains more soluble nitrogen, more ammonia, and a larger amount of soluble organic nitrogen compounds. Possibly some of the phosphoric acid in the deep stall had passed into the form of the insoluble double phosphate of magnesia and ammonia.

Fermentations are caused by Microdemes.

Undoubtedly the true way of looking at the matter is to admit that the fermentations of dung are due to the presence of various

living ferments, somewhat in the same way that the alcoholic fermentation of sugar is due to the presence of the yeast plant. It was in fact observed long ago by Leuwenhoeck, that dung contains not only germs, but fully developed microscopic organisms. This observation has repeatedly been verified, and it can readily be conceived nowadays how it is that loose dung may undergo active and violent fermentation, such as would be impossible in case the materials were firmly compacted or mixed with a considerable amount of earth or other inert matter, and especially if they were packed in a silo or drenched in a pit.

Some Kinds of Ferments need Air.

Pasteur has shown that two distinct classes of microscopic organisms are concerned in fermentations. The members of one of these classes are active only in presence of air or free oxygen gas, while those of the other class require neither air nor free oxygen for their support, since they can obtain a sufficiency of this particular kind of food by taking it from organic matters that contain oxygen as an essential constituent. Ferments of the kinds that need air have been designated as *aerobic*, and those which act in the absence of air are called *anaerobic*.

The anaerobic ferments — viz. those which can live without air — act to break up pre-existing compounds into new and simpler forms, and when this work has been accomplished their activity must cease. But in case the fermenting substance is exposed to air, decay will go on indefinitely. In other words, aerobic ferments will live and thrive upon it continually, even upon the disorganized materials which have been exhausted, so to say, by the anaerobic ferments. Thus it happens, when the conditions are such that the external air cannot gain access to manure, that the internal or anaerobic fermentation of the constituents of the manure may speedily run its course and wellnigh cease.

It is to be presumed, also, that the carbonic acid and other products which are generated during the anaerobic fermentation, and which cannot readily escape from the mass of manure, must soon permeate every part of it, and help to exclude air, and so tend to repel the aerobic ferments, even if this carbonic acid may not act directly to destroy the ferments when present.

The power of carbonic acid to check certain forms of decay was clearly recognized long ago, and strongly insisted upon. The distinguished chemist and physician, Macbride, writing in 1764, inti-

mates that he has found "very strong reasons for believing that carbonic acid is the grand preserver of animal fluids from putrefaction." This belief he proceeded to justify by several well-considered experiments. He dwells even on the power of carbonic acid to "restore sweetness," an effect which, as we now know, must depend on the destruction by the carbonic acid of some of the microdemes which cause decay. One of Macbride's experiments was to hang a bit of putrid mutton, "cut thin, so that the vapor may have power to pervade it," in the mouth of a vessel in which molasses wash was fermenting, in such manner that the meat should not touch the liquid, but be continually enveloped with the gas developed from it by the fermentation. After having been thus left over night, the meat was found next morning "plumped up, sweet, and firm."

So, too, John Davy remarked, that "the products of putrefaction, viz. carbonic acid and carbonate of ammonia, exert [to a certain extent] an antiputrescent action."

Pringle observed, as long ago as 1750, the fact, of a somewhat different order from the foregoing, that an increase of acidity may check putrefaction. He says: "When farinaceous vegetables were examined, viz. white bread in infusion, and decoctions of flour, barley, and oat-meal, they did not at all retard putrefaction (of flesh) at first; but after it was somewhat advanced, they checked it by turning sour. . . . . By a long digestion, the acidity became considerable, which by conquering the putrescency of the flesh," etc.

For this matter, the preservative power of acids, such as vinegar, is well known and familiarly made use of in domestic economy.

For exciting the hot, active putrefaction of manure, the presence of a certain amount of air seems to be needed, while for slow, regular fermentations, such as may occur in impacted manure, for example, little if any air is necessary, since, as has been said, the organisms that occasion such fermentations are able to procure oxygen enough for their support from that which is held in actual combination by the organic matters in the manure. Pasteur has shown that the air in a closed flask, partially filled with urine, may be deprived of all its oxygen in the course of a few days through formation of carbonic acid by the action of microscopic organisms whose germs were floating in that air. But on charging a flask of urine with air that has been ignited to destroy the germs naturally contained in it, the urine will remain almost without change for

years, and comparatively little of the oxygen in the flask will be converted to carbonic acid.

In one case, Pasteur found that the air which had thus been left in contact with urine for three years contained 11½% of oxygen, 11½% of carbonic acid, and 77% of nitrogen. He found that blood also, as well as urine, could readily be kept, in contact with air, undecomposed, if only pains were taken to destroy the germs in the air and prevent the access of others.

In another experiment, oak sawdust, that had been boiled with water, was left in contact, at 86° F., with air that had been ignited. But after a month had elapsed, this air was found to contain 16¼% of oxygen, 2⅓% of carbonic acid, and 81⅓% of nitrogen. Whereas, on repeating the experiment under ordinary conditions, i. e. with unignited air and unboiled sawdust, a large amount of oxygen was speedily removed from the air, and carbonic acid formed.

Fermentations differ according to Circumstances.

It may be laid down as a rule, that the fermentations of manure will vary materially according as more or less air has access to the heaps, and as more or less water is contained in them; or, in other words, according as circumstances favor the growth of one or another kind of microdeme. It is with manures somewhat as it is with soils, only that the fermentations of the manures are more evident and pronounced. In dry, porous heaps of manure there may be rapid wasting of the carbonaceous matters by processes of oxidation, as will be explained under Composts. On the other hand, when fresh urine comes in contact with putrid urine, the urea contained in the former will quickly be changed to carbonate of ammonia by the action of a peculiar organism with which the putrid urine has become charged. And when air is excluded from manure, there may occur either such fermentations as produce marsh gas (CH_4), or those which generate butyric acid and other kinds of acids, while free hydrogen gas is evolved. Sometimes the lactic fermentation may occur. Ordinarily, several kinds of fermentation appear to progress simultaneously, or, at the least, to succeed one another rapidly.

The presence of butyric acid has often been detected in fermenting manures, in decaying fruit, flesh, and pulse, as well as in the soil, and there are reasons for believing that putrefaction, properly so called, may often be little more than a butyric fermentation. But Pasteur has shown that the organisms which cause the butyric

fermentation, far from needing air, can live and multiply in organic matters, even when no trace of free oxygen is present. Indeed, air destroys these organisms, and the admission of it to materials upon which they are at work will arrest the fermentation.

Manure may spoil in Loose Heaps.

The system of compacting cow manure, just now described, offers a strong contrast to the common habit of leaving horse manure to spoil itself by rapid fermentation in dry, loose heaps, and indicates the absurdity of this habit. Horse manure is not only dry naturally, but it is, comparatively speaking, highly nitrogenized, at least when the animals are fed with grain. Consequently, it decomposes with great rapidity, and there is an enormous loss of nitrogen, not only as ammonia, but as free nitrogen gas. Boussingault observed of a lot of horse manure, the dry matter of which, when in the fresh condition, contained 2.7% of nitrogen, that it lost nearly two thirds of its nitrogen in the process of decay. After complete decomposition, the dry matter of this manure contained only 1% of nitrogen.

It would undoubtedly be much better to keep the dung slightly moist, and trodden down compactly, as is in fact sometimes done in this country by means of swine in barn cellars. In the main, however, not half enough attention is given to the care of horse dung. Many farmers are apt to overlook the fact, that it is usually far more valuable than cow dung when fresh, and to forget that it spoils so easily.

A system of compressing horse manure into bales, as if it were hay, in order to facilitate its transportation, has for several years been practised at some of the larger stables in New York City, though very little appears to have been published with regard to the utility of it. An opinion seems to prevail, however, among practical men, that the baled manure has been found useful in field practice. It is probable that this particular product is much drier than the impacted Saxon cow manure above described.

Another instance of impaction is seen in the case of sheep manure from stables where the droppings and litter have been left for a long time under the animals, as is usual in many localities. It is very questionable, however, in this case, where the manure is comparatively dry, whether a large part of its most valuable constituents may not have been destroyed by improper fermentations. Nitrification is known to occur, however, in such sheep manure, and to a very considerable extent.

Pounds of Food eaten indicate Yield of Manure.

The amount of manure produced by animals may readily be computed approximately from the amount of food which they have eaten (or are to eat), and the quantity of straw that is employed for bedding them. Heiden has given several instructive examples of this method of computation. In the case of horses, it appears that some 47⅓% of the dry matter in their food passes out from them in the solid and liquid excrements, and that the percentage of water in these excrements amounts to 77½ on the average; so that in the total excrement there is about 22.5% of dry matter. Whence it appears that, from every 100 lb. of dry matter eaten, 210 lb. of fresh manure will be produced,

$$22.5 : 100 :: 47.33 : 210,$$

or, for each pound of dry matter in the fodder there is obtained rather more than 2 lb. of manure.

In case the animals were standing all the while quietly in their stalls, the weight in pounds of fresh excrement produced by them would be got by simply multiplying the number of pounds of dry matter in their fodder with the factor 2.1. To the product thus obtained would be added the number of pounds of straw that have been expended in bedding the animals, say 6½ lb. per diem on the average. But in case the animals are worked, there must be subtracted whatever dung and urine have been dropped outside the stables.

If, for example, it be assumed (with Heiden) that a horse works 260 days of 12 hours each in the course of a year, or 130 whole days, it may be admitted that 235 days have been spent in stall; and by multiplying this number with the daily product of dung, as above obtained, and adding the yearly expenditure of straw, there will be got an approximation to the yearly product of manure. Heiden makes out in this way that a well-fed working horse will produce about 50 lb. of manure a day, or some 6½ tons in the year, as above stated. Of course, much must depend in each particular instance on the liberality with which straw is used for bedding the animals.

In the case of cows or other neat cattle, it has been observed that the animals void some 48% of the dry matter of the food in the liquid and solid excrements, and that the fresh excrements contain on the average 87½% of water and 12½% of dry matter. But

$$12.5 : 1 :: 48 : 3.84,$$

so that in this case we have the factor 3.84 with which to multiply the number of pounds of dry matter in the fodder in order to obtain the number of pounds of fresh excrement. To the product of this multiplication must be added, as before, the straw used for bedding, which for animals kept in stall should amount, according to Heiden, to not far from one third the weight of the dry matter of the fodder.

Hence, an ox of 1,000 lb. weight, consuming 27 lb. of dry matter per diem, will produce in a day $(27 \times 3.84) + 9$ lb. of manure, i. e. nearly 113 lb. And in a year he will produce some 20 tons. In the same way it may be concluded that young cattle of 500 lb. weight, consuming 16 lb. of dry matter per diem, will produce in a year 12 tons of manure apiece. Where cows are pastured in summer, or where they are kept up of nights without bedding, allowances must of course be made both for the time they are absent from the stable and for the straw that has been saved.

For sheep, it may be assumed that 49⅓% of the dry matter of the food goes into the excrements, and that the fresh excrements contain 73% of water and 27% of dry matter. Hence the factor 1.83, which, when multiplied into the dry matter of the fodder, will give the weight of the fresh excrement, for

$$27 : 1 :: 49.33 : 1.83.$$

Here again the weight of the straw used for bedding must be added to the product of the multiplication. Thus, a 60 lb. sheep eating 2 lb. of dry matter daily, and bedded with three fifths of a pound of straw, will produce about three quarters of a ton of manure in a year. The amount of manure would naturally be less in case the animals were pastured or bedded only part of the year. For sheep in fold, the daily product of manure may be got by simply multiplying the number of animals by 3.7 (= 2 lb. of dry matter multiplied by 1.83, as before).

Well-rotted Manure.

In the light of what is now known as to the chemistry of the subject, and particularly in view of the practicability of supplementing farm manure nowadays with artificial fertilizers, it is safe to say that most farmers unduly esteem old fermented manure, which has been forked over repeatedly, and has rotted until it has become a soft black mass. There can be no doubt as to the great fertilizing power of this fermented dung, nor of the fact that it admits of being distributed more evenly and worked into the soil more thoroughly

than long manure. In general, it will be less likely than fresh dung and urine would be to excite rank growth, such as would cause a grain crop to run to leaf. There can be little doubt, moreover, that very old manure, when once it is distributed, is one of the best possible breeding-places of those useful organisms which, as is now known, are the moving cause of nitrification; whence it follows that the application of old, thoroughly rotted dung may be regarded as one exciting cause for fermenting and fertilizing the inert humus which is already in the fields. Yet it is none the less true, that chemists, almost without exception, are in favor of applying dung and urine to the land in the freshest possible state; and that many of the most successful and celebrated among practical agriculturists are entirely of the chemists' opinion.

The moment any kind of manure begins to ferment, no matter where, it gives off some of its substance in the form of gas; but if the fermentation occurs within the soil, it will be gradual, and the products of decay can be utilized by the neighboring plants. Besides, fresh manure, in fermenting within the soil, will act upon the soil advantageously in various ways. It will not only play the part of a ferment, and so tend to decompose the inert nitrogen compounds of the humus, but the products of its decomposition will act as disintegrating agents upon the insoluble portions of the soil. There are, in short, many reasons for believing that a larger proportion of the useful constituents of mere dung can be utilized by burying it in the soil when fresh, than if it be left to ferment in heaps. The horse manure just now alluded to may be cited as a case in point. Everybody admits the efficacy of horse dung from stables when it is applied to the soil in the fresh unfermented condition, but there are many farmers who justly set no great value on horse manure from which the goodness has been "burned out," as the term is, in the process of hot fermentation.

Rankness of Fresh Manure.

There are nevertheless several practical considerations which count in favor of using well-rotted manure, especially in case the manure is to be used on grain by itself, and not in conjunction with an artificial fertilizer. Many practical men have urged that fresh manure, even if it does not actually injure the crop to which it is applied, may still tend to the production of stems and leaves, rather than of seeds and fruit. There is a wide-spread belief that, while fresh manure may perhaps be best for forage crops, well-rotted

manure or compost is better suited for the production of grain or seeds; and, on this account, in many regions manure is applied by preference to a preparatory crop rather than directly to grain.

But, manifestly, the rankness of fresh dung and urine could be controlled and utilized by applying the manure in small quantities and supplementing it with artificial fertilizers of kinds appropriate to the crops that are to be grown.

This same fear of the forcing effects of fresh manure has often led farmers to apply it in autumn to land that is not to be sown until the next spring. In this way the manure is brought to a condition not unlike that obtained by rotting manure in heaps; though in all probability the mitigation of the manure must depend on an actual loss of highly useful constituents.

Boussingault was disposed to attach considerable importance to the influence of climate upon the decomposition of manure in the soil. He sums up as follows. In warm damp countries it may be conceived that it is a matter of indifference whether farmyard manure is put into the ground quite fresh, or more or less thoroughly decomposed; for, thanks to the heat of the climate, the decomposition will be rapid enough anyway. But it may be otherwise in cold climates where the temperature which excites and maintains vegetation is of comparatively short duration, and must at once be taken advantage of. In such places the ground is so cold that during a great part of the year organic matters buried in it would be preserved with comparatively little change. Under such climatic conditions, there is no doubt that well-decomposed manures are preferable to those that are fresh and long. The extensive use of liquid manures in Switzerland, he suggests, is an illustration of the estimation in which quick-acting fertilizers are held in places where immediate advantage must be taken of a short summer.

Merit of Fresh Manure.

Having in view the climate of Central Europe, Walz, a noted German agriculturist, wrote with a great deal of force in favor of carrying fresh dung to the fields. He remarks upon the fact, that, upon many South German farms, after the manure has all been hauled out in autumn, the dung-heaps are left to accumulate during half a year, not being disturbed again until spring; whereas during the summer season the manure is often hauled out upon the fallow fields after having lain in the yard no longer than 5 or 6 weeks. But it is noticed that under these circumstances there is always

much more manure to haul from a given number of cattle in summer than in winter, — in places, that is to say, where the cattle are all the while kept in stall.

Attempts have been made to explain this fact, on the assumption that an increase of dung is caused by the green food which is given to the cattle in summer. But this idea is refuted at once by the facts, that the dung-heaps increase just as fast during April and May, before the animals get any green food, as they do afterwards, and that the rapid accumulation of dung in summer is just as well marked in the case of fattening cattle and draught oxen, that have received no green food. Manifestly the chief cause of this apparent increased production of dung is, that a smaller proportion of the dung is wasted by decay in the heaps when the heaps are new and small.

But, as Walz urges, it is good practice to carry the fresh dung to the field for the mere sake of availing one's self of the increase of bulk; for the fresh manure expends to better advantage, i. e. it may be made to fertilize a larger surface, than if it were left to shrink in the barnyard heaps.

He narrates how his own attention was emphatically called to this subject, when he was a young man, by the circumstance that he had a field so situated that the manure had to be hauled upon it in winter. He computed how many loads of manure would dress the field, and proceeded to have the manure hauled out in February when the ground was frozen. He carried out 36 wagon loads in all, and had them piled up in two heaps. But when he came to spread the manure, seven weeks afterwards, there were only 24 wagon loads of it to be found.

His farm was at that time a good deal run down, and on the system which he had previously been following of never spreading anything but half-rotted dung, — in the belief that manure was best when used in that condition, — he had each year been unable to make manure enough to dress all his fields.

Hence it happened that he fell into the habit of hauling out fresh dung to make up the deficiency, so that he frequently had opportunity to compare the effect of the two kinds of manure where they were put into competition with one another upon the same field.

Indeed, it even happened that the fresh dung, being stretched as it were to the utmost to make up the deficiency, was spread rather thinner than the rotted dung. But Walz was never able to

detect any difference either in the appearance of the crops, or the number of sheaves of grain, or in the yield of dressed grain.

So that by taking the two hints, especially the one offered by the shrinkage of the heaps of dung in the field, he was led to carry out methodically all the manure of the farm in the freshest possible condition; and the longer he practised this system, the more firmly was he convinced of its great superiority. From the time when he seriously began to use all the manure in the fresh state, he had no trouble in getting enough of it to dress all his fields.

Several writers have urged that the character of the soil must be considered. Fresh, strawy manure, they say, may be safely applied to sandy soils, where it will decompose readily enough; while upon clays or heavy loams the fresh manure might not serve nearly so good a purpose, because the compactness of such soils tends to exclude air from matters buried in it.

Shrinkage of Manure Heaps.

The shrinkage above spoken of must often be very large. Gazzeri found long ago that horse manure lost in the course of four months more than half the dry matter that was contained in it before the putrefaction. Several of the older agricultural writers have insisted that 100 loads of fresh manure may be reduced to 70 or 75 loads after two or three months' fermentation, and even to less than 50 loads at the end of a year. Sir Humphry Davy, in his turn, urged that "dung which has fermented so as to become a mere soft, cohesive mass, has generally lost from $\frac{1}{3}$ to $\frac{1}{2}$ of its most useful constituents." It must be admitted that Davy's idea is in no wise improbable, for it is known that a great deal of nitrogen is lost from fermenting manure in the gaseous form, even in cases where none of it goes to waste as ammonia. It is known also, that much of the nitrogen in fermented manures has passed into the inert humus-like condition.

Voelcker, in his elaborate experiments on fresh and rotted dung, observed that fresh dung loses practically in the process of decay from 26 to 60%, and more, of its original weight; and Wolff records a loss of 54% in the case of an 80-ton heap of cow manure that was left for a year freely exposed to sun, wind, and weather. The loss was in no sense due to evaporation of water, for, on stating the matter in terms of dry substance, i. e. fresh and rotten manure from which all water had been dried out at 212° F., it appears that the dry manure had lost $66\frac{1}{4}$% of its weight. This fact of an absolute

loss of substance must be kept in view whenever analyses of fresh and of rotted dung are compared, for the figures of the analyses are merely relative, and they often give no very distinct indication as to how much of any particular ingredients has been lost.

Voelcker's Analyses of Farmyard Manure.

A brief abstract of Voelcker's analyses of farmyard manure (mixtures of horse, cow, and hog manure) is here given. But it is to be remarked that two separate lots of manure were operated upon, — the samples described as six and eight months old being different from the others.

	Fresh Manure, 14 days old. Nov.	From Heap 3½ mo. old. Feb.	Under Cover 3½ mo. Nov. to Feb.	Spread 6 mo., from Nov. to May.	Well Rotted. 6 mo. old.	Well Rotted. 8 mo. old.
Water	66.17	69.88	67.82	80.02	75.42	78.90
Soluble organic matters	2.48	3.86	2.68	1.16	3.71	2.70
Soluble inorganic matters	1.54	2.97	2.12	1.01	1.47	2.06
Nitrogen						
Soluble in water	0.15 } 0.64	0.27 } 0.74	0.17 } 0.75	0.08 } 0.54	0.30 } 0.61	0.15 } 0.21
Insoluble in water	0.49	0.47	0.58	0.45	0.31	0.06
Phosphoric acid						
Soluble in water	0.14 } 0.32	0.14 } 0.32	0.15 } 0.45	0.09 } 0.27	0.18 } 0.45	0.06 } 0.12
Insoluble in water	0.18	0.18	0.30	0.18	0.27	0.06
Potash	0.67	1.23	0.88	0.42	0.49	1.08
Lime	1.19	1.84	1.92	1.97	1.78	2.27
Magnesia	0.15	0.05	0.08	0.09	0.14	0.04
Ammonia, free . .	0.08	0.02	0.22	0.01	0.05	0.02
Ammonia, as a salt .	0.09	0.06	0.54	0.05	0.08	0.05
Nitrates	None.	Traces.	Indistinct traces.	None.	None.	Decided traces.

As here given, Voelcker's results have been very much condensed and curtailed. See Heiden, II. 128.

In Dr. Voelcker's opinion, as stated some years after the date of these analyses, "Neither fresh nor rotten dung contains an appreciable amount of free ammonia. Under good management dung loses none of its essential fertilizing constituents, and neither sun nor wind expels any volatile ammonia compounds from dung. It appears, therefore, quite unnecessary to keep dung in closed buildings. In localities where much rain falls, and a sufficient amount of litter cannot be used to absorb the liquid portion of the manure, it is advisable to have the dung-yard roofed in and the sides open; but where sufficient litter can be spared in the making of the manure to retain, even in rainy weather, the liquid portion, it is even unnecessary to put a roof over the dung-pit. No loss in fertilizing matter is experienced when dung is carted and spread upon the field as soon as it is possible to do so after it is produced." With regard to the increase of the percentage proportion of soluble nitrogen com-

pounds and of soluble organic matters in manure as it decays, Wolff has urged that this increase can only occur to an appreciable extent in exceptional cases, as in firmly trodden manure kept in very moist pits, where air is excluded. Under such conditions as these, processes of chemical reduction will occur; sulphides will be formed, and apparently ammonium compounds also.

It is of interest to recall the fact, that the simultaneous formation of sulphides and ammonium compounds has sometimes been noticed in the humus of peat bogs. In Wolff's own experiments, where cow manure was allowed to decay in heaps, there was a considerable diminution of soluble nitrogenous and organic matters, and of ammonia also, according as the process of decay progressed.

The question whether dung shall be applied in the fresh condition, or rotted, appears to be intimately connected with another which has not a little exercised the minds of farmers; viz. whether it is best to manure heavily and seldom, or lighter and more frequently. The general conclusion seems to have been, that, excepting cold, moist land, where large quantities of manure may occasionally be applied for the sake of improving the physical condition of the soil, it is almost always preferable to manure rather lightly and frequently.

Shall the Land be manured, or the Crop?

It would appear, however, that this tendency dates only from the time when artificial fertilizers came into general use. Nowadays it is customary to use powerful soluble fertilizers of quick action, and to apply no very large quantity of them at any one time. As has been said, the idea now is to manure the present crop, while formerly every one thought and spoke of manuring the land. The modern idea is justified by what has been learned in recent years as to the peculiar merit of fresh manure; as to the destruction of the nitrogen in manure, both by fermentation and by change to inert humus, with the lapse of time; and as to the conversion of the dung nitrogen to nitrates, which may leach out of the land unless the roots of a growing crop stand ready to absorb and consume them.

Some of the experiments that have been made with Peruvian guano applied by successive instalments illustrate very well the significance of fresh manure, for the constituents of guano are closely analogous to those in fresh animal excrements, and they speedily undergo change in the soil. It is often complained of guano, that its effects are fugitive, but the real trouble is evidently with the

clumsy methods of applying it which are in ordinary use. So it is with dung and urine, and if it were but possible to bring these fertilizers to the fields continually in appropriate quantities in the fresh condition, the best possible utilization of them (chemically speaking) would doubtless be obtained.

Stoeckhardt applied guano at the rate of 1½ Centner to the Morgen (= 0.631 acre), and obtained the following relative weights of sheaves of oats.

	In the Year 1857.	In the Year 1858.
Guano all applied at seed-time	100	100
Half at seed-time and half before the crop had begun to shoot	147	113
One third at seed-time, one third before shooting, and one third before blossoming	168	133

In 1861 his experiments resulted as follows: —

	On a Poor Sandy Soil.	On a Strong Clay Soil.
Guano all applied at seed-time	100	100 (assumed.)
Guano applied twice at seed-time	131	134
Guano applied after the seed once	100	100 (assumed.)
Guano applied after the seed twice	115	112
Guano applied after the seed thrice	162	161

Litter needs to be Rotted.

Practically, as a mere matter of labor, stowage capacity, and convenience, it would be difficult for most farmers to bring more than a small portion of their barnyard manure to the land in the fresh condition.

Moreover, fresh stable manure almost always contains in practice an admixture of straw, cornstalks, and other "long" litter, which would seriously interfere with the application of the manure to the land, and which render it unhomogeneous also. It is true that, on some kinds of land, the long manure might do good, physically speaking; i. e. many a heavy soil might be lightened by means of it. But, to say nothing of the trouble of incorporating it with the soil, it might often happen on soils in good tilth, in case unrotted manure were buried directly, that a good part of the straw would escape decomposition, and consequently exert no immediate fertilizing action. It might even do serious harm by lightening the land unduly. The dung alone would go to nourish the present crop, and an entire season might elapse before the straw had decomposed sufficiently to render its constituents fit food for plants.

It has sometimes been urged that these last considerations do really indicate the limit to which the fermentation of long manure may be profitably pushed; to the point, namely, where the straw or other litter begins to lose its integrity, and admits of being torn apart with scarcely any effort.

It is probable that this point of incipient change is really the one to be aimed at as the point of greatest advantage, all things considered, though it is manifest that only a comparatively small proportion of a year's stock of manure can be employed in just this or in any other one particular condition. The convenience of each farmer will of course determine how much of his manure he will carry out green and how much after fermentation. But it is none the less desirable that the best way of doing the thing should be kept in view and striven for.

Merits of Rotted Manure.

Boussingault, for his part, did not hesitate to insist that there may be "an immense advantage" attending the fermentation of manure, in that the product, provided that the fermentation has been discreetly controlled, may be of greater value under a smaller bulk and less weight. He urges the very important saving of carriage in the case of the fermented dung, as, for example, when it has lost a third of its weight by the process.

The remark is true, not only in respect to the hauling out of manure, but also as to the distributing of it. It is possible, of course, to lay long strawy manure in the furrows as fast as they are made so that the plough may cover it in at the next turn, as is often done in fact in certain districts; but the labor thus expended must usually exceed in value whatever chemical substance would have been lost in case the manure had been fermented, and the waste of labor is palliated rather than done away with when such manure is worked into the land by means of machines, such as disk harrows or the like.

The most thoroughly rotted manure at one's disposal would naturally be put upon light soils, and upon those highly cultivated fields which are to be managed as if they were gardens; the long manure would be relegated to heavy land and to crops not requiring specially careful management; while for a large portion of the farm the half-rotted material just now described might be preferable, all things considered, to either of the others. It is to be remembered withal, that, from the discussion on page 321 of the experiments on

the comparative value of nitrates and ammonium salts as plant food, it appeared that some kinds of crops may prefer the nitrogen in old manure to that in fresh manure, and *vice versa.*

One reason why thoroughly rotted stable manure is so much esteemed is, that, taking the whole mass of it into consideration, it usually acts quicker than long manure. A larger proportion of each ton of the mixed matters is already in a condition fit to be taken up by the roots of plants.

This consideration is doubtless more important in the case of wheat and other grain crops, than in that of some other kinds of plants, and it was more important formerly, in the days when artificial fertilizers were not to be had, than it is now. The life of the grain plants is comparatively short, their growth is completed in the course of a few months, and the period during which they can consume manure may be counted by weeks. Hence it may happen, that, while some part of the fresh manure would act only too speedily, the decomposition of the remainder might not be rapid enough fully to supply the wants of the crop. But in the case of plants like Indian corn and potatoes this objection would have less weight.

In dry seasons, and particularly for light soils, the quick action of well-rotted manure would, however, have the merit of giving the crop a start, so as to enable it the better to survive the subsequent hardships. The humus of the well-rotted manure would, moreover, often serve a better purpose in case of drought than the long unfermented litter from which it was derived.

Undoubtedly one chief reason why short manure is thought to be better than long depends upon the fact, that, provided the rotting has been thorough, it is really an enormously concentrated manure. Much of the shrinkage in volume which occurs when manure ferments tends simply to concentrate the manure through loss of non-essential matters, though, as has been urged already, some part of the diminution is due to an actual waste of useful ingredients.

As Walz has suggested, the loss of manure by decay may be seen very clearly by contrasting the effect of folding sheep with the effect obtained by using sheep manure that has been hauled from the stable.

In his practice, 200 sheep were folded for 240 nights, on the average of years, upon 18 Morgen of land. During the remaining

125 days of the year the sheep were kept, upon equally good food, 80 whole days and nights in stall, on the average of years, plus 45 nights. When in stall, the sheep were littered with from one third to one half a pound of straw per head and per day.

In May the sheep manure was hauled out and spread for a rape crop upon three Morgen of strong land contiguous to the land that had been folded upon. But during the six years that comparisons were made, the rape crop was always as good upon the land that had been simply folded upon as upon the land that had been dressed with the sheep dung, and in two instances the folded land carried better crops than the other; and precisely the same effect was noticed in regard to the winter grain that succeeded the rape, and in respect to all the crops that followed the grain in the rotation.

Hence it appeared that the stall manure of ⅓ the year went only one sixth as far as the folding of ⅔ of a year, although 80 days as well as nights are to be counted in favor of the production of the stall manure, and although 124 cwt. of straw were commingled with the dung, and although the dung and straw were trampled down hard by the animals, so that the access of air was much less than it would be in a mere heap. The loss through decay was equal to the whole of the straw and half the droppings of the animals.

Straw must be Rotted.

Per contra, the importance of rotting the straw in stable manure is often insisted upon by practical men in grain-growing districts.

In laying down rules for the treatment of manure, some of the Western New York farmers have enjoined, 1st, that the barnyard should be so arranged that no part of the manure can run out from it; 2d, that straw enough should be used to absorb all the liquid portion of the manure; and, 3d, that the strawy mixture when hauled to the fields in the spring should be piled in rather large, high heaps, with square sides, and with the top somewhat hollow in order to hold water.

They say that, if the top were built rounding, or slanting like a roof, so little water would soak into the heap that the straw would not rot. Even when a heap of very strawy manure is well built, with a saucer-like depression on top, its sides will not decay. In order to rot the straw in them, the sides may be pared off after a while and thrown on top. A heap of strawy manure that has been well built in the spring will be in condition to be cut with a spade

by July. Practically it would be used in August or September on winter grain.

It is to be observed that such long, dry manure as this of which the New York farmers speak would not profit by being kept under cover. Indeed, it would be apt to suffer injury if the heaps just spoken of were made in sheds. Unless the manure be at least three quarters cow dung, the keeping of it in sheds is said to be inadmissible. Theoretically sheds might serve well enough for keeping the manure from cows in New England, and yet be of no use, or be worse than useless, for the manure of farms that are devoted to grain-growing, unless indeed the arrangements of the grain farm are such that the straw shall be fed out to stock in conjunction with some kind of wet food, like distillery refuse, or the potato slop and beet-root pulp of Europe.

The tendency of manure to injure itself by firefanging is one danger to be avoided, as well as the risk of leaching by rain. Sheep manure or horse manure left to itself under a shed would be liable to firefang. And, on the other hand, if manure were exposed too long to an excess of moisture, it might pass into a cold, sour condition, and form faulty humus analogous to that in a peat bog. It has been urged indeed by Reiset, that, when organic matters decay under water, they are specially liable to lose their nitrogen in the form of nitrogen gas; though it must be said that this observation seems hardly consistent with numerous other experiments by various chemists, which show that free nitrogen goes to waste more particularly from decaying materials which are freely exposed to the air.

From the foregoing it would appear that, although some system of ensilaging manure might be theoretically excellent, the plan is hardly called for as regards cow manure, which can be managed fairly well in less costly ways; while for manures that contain much straw that needs to be rotted, ensilaging is plainly inadmissible. For preserving fresh human excrements, silos may serve a good purpose. The Chinese have, in fact, used them to this end in their rice-fields time out of mind.

Nitrates hardly form in Dung-heaps.

It is not easy to speak in any very definite or authoritative way about the formation of nitrates in the dung-heap. Undoubtedly some nitrates and nitrites are formed near the surface of old heaps of manure, in spite of the fact that rotting manure must act as a

reducing agent, and so tend to hinder their formation. Voelcker found considerable quantities of nitrates, though not enough to estimate quantitatively, in the dark brown liquid, leached out by rain, that drained away from an old, well-rotted heap of manure, consisting of a mixture of the dung of horses, sheep, and stall-fed cattle; the inference being that the nitric ferment was able to live and work at or near the surface of the heap.

But in a still darker and much more concentrated dung liquor, that had drained out of a heap of fresh horse, cow, and hog dung, he could detect only traces of nitrates. He noticed, also, that the liquid from the fresh dung-heap contained less than half as much combined ammonia as the other, manifestly because a good part of the organic nitrogen compounds natural to the fresh manure had not yet suffered decomposition.

Alexander Müller found that, while urine that had been diluted with a great deal of water nitrified rapidly without emitting any odor, a quantity of fæces that had been mixed with 400 parts of water continued to give off offensive odors of putrefaction for months, and was only very slowly subject to nitrification.

The common practice of turning over manure, so as to expose it to the air, that is to say, the tossing up of the manure from a compact heap into a loose heap, must tend to the formation in time of nitrates in some parts of the heap, and may have been in some part justified formerly by this consideration, though commonly the forking over is resorted to either to check fermentation when the heap is in danger of getting over-heated, or to excite new fermentation when the first quick action has abated, in order to hasten the decay of the litter.

In general, it may be said that the purpose of the forking is to check or promote, i. e. to control, fermentations of other kinds than the one which causes nitrification. It is not improbable, indeed, that the "tempering" of the manure, i. e. a mitigation of its rankness by changing the character of the nitrogen compounds originally contained in it, may have been of considerable importance at a time when the farmer's first thought was to grow heavy crops of grain by means of farmyard manure. For, in order to obtain such crops, care has to be taken to avoid too rank a growth of straw. In point of fact, however, next to nothing is known about the changes which the nitrogen compounds in fresh manure undergo when the manure ferments slowly in a moist heap.

A good deal used to be said about the loss of ammonia during the fermentation of manure, and numerous receipts for saving this ammonia by means of gypsum, or copperas, or sulphuric acid, or the magnesium compounds in Stassfurt potash salts, have been published. The utility of these additions has already been set forth; but, with the exception of the actual stable floor or standing room of the animals, it does not appear that much ammonia is lost from cow manure during the ordinary conditions of fermentation.

The less moist horse manure, when left to ferment in loose heaps, gives off, as every one knows, large quantities of ammonia. For the sake of the object lesson, German farmers have occasionally led air from a horse stable over or through porous materials saturated with muriatic acid, and have evaporated to dryness the solution of ammonium chloride thus obtained, in order to exhibit the concrete substance. I have myself seen, at a cattle-show in Prague, a massive block of ammonium chloride which had been obtained in this way. But from cow manure, and the ordinary mixed manure of the farmyard, so long as it is kept moist and compacted, no very pronounced fumes of ammonia arise. Indeed, it is often difficult to detect the presence of any ammonia by means of test papers around heaps of manure which are properly cared for. It will probably be found one day, that the reason why the ordinary practice of keeping manure heaps moist is correct may depend in part upon the fact that, in this event, the nitrogen compounds cannot decompose in such manner as to form ammonia gas. It is not impossible, however, that some ammonia is formed all the while, and retained as humate of ammonia, which in its turn is changed to the condition of inert humus, as was mentioned on page 404.

END OF VOL. I.